KARLSRUHER NUKLIDKARTE - COMMEMORATION OF THE 50TH ANNIVERSARY

9 – 10 December 2008, Karlsruhe, Germany

Heaviest Nuclei

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&

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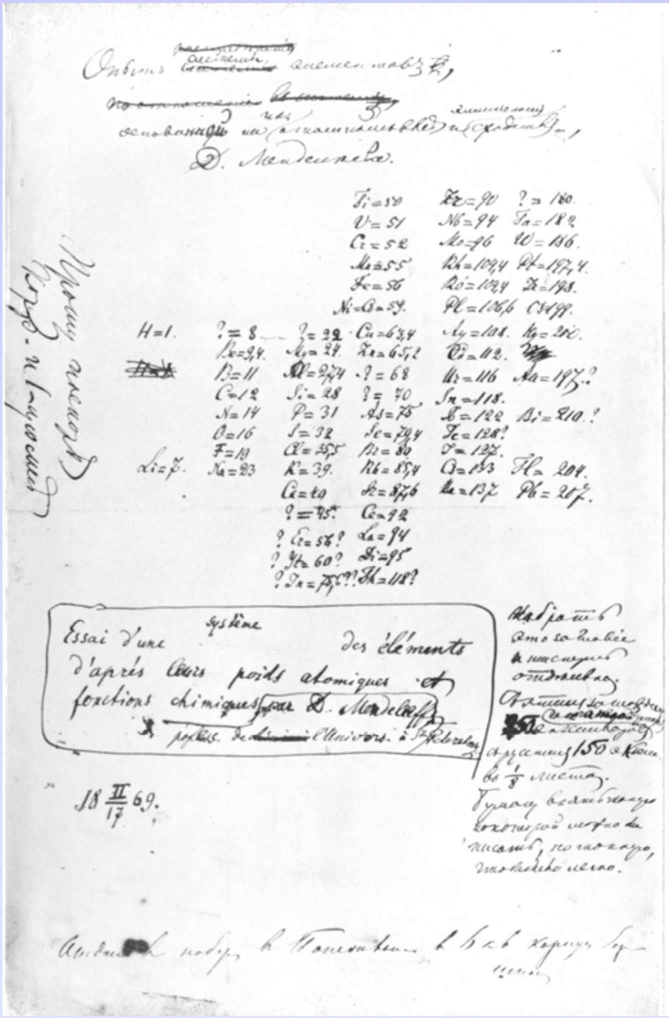
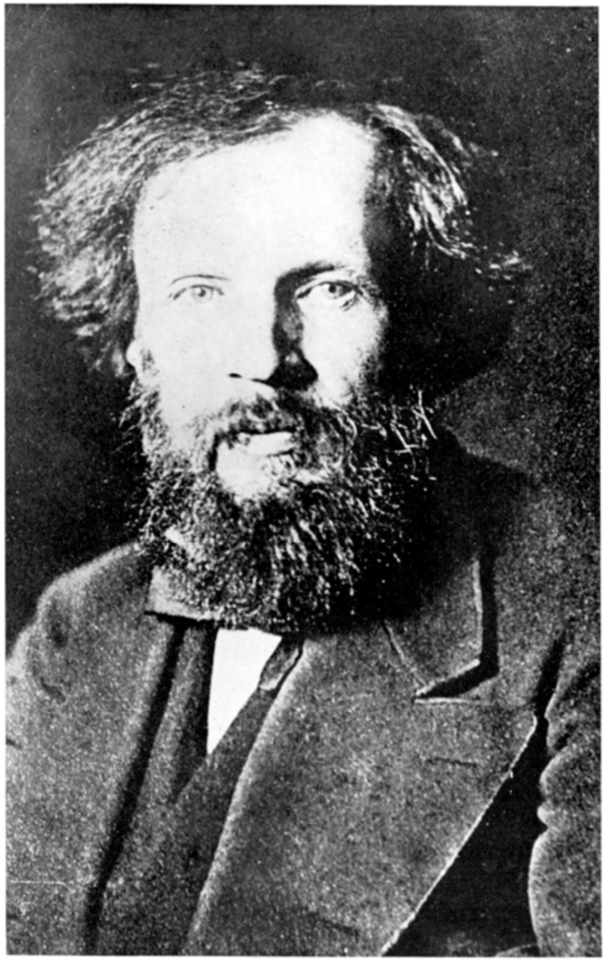
Periodic table of the elements
Dmitri Mendeleev (1869)



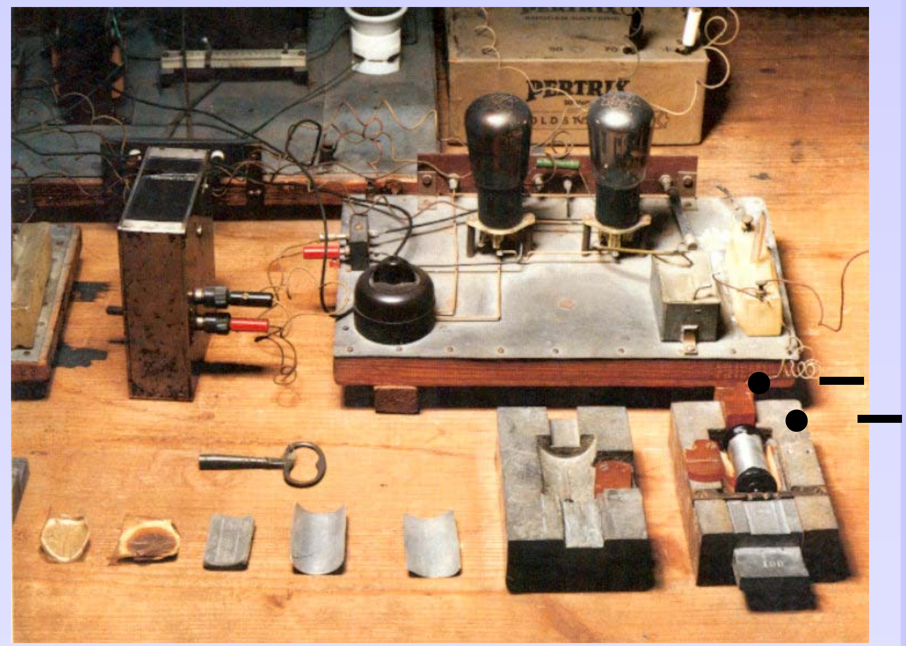


In 2009 the scientific community will mark the 175th birthday of D.I. Mendeleev

1934: search for transurane

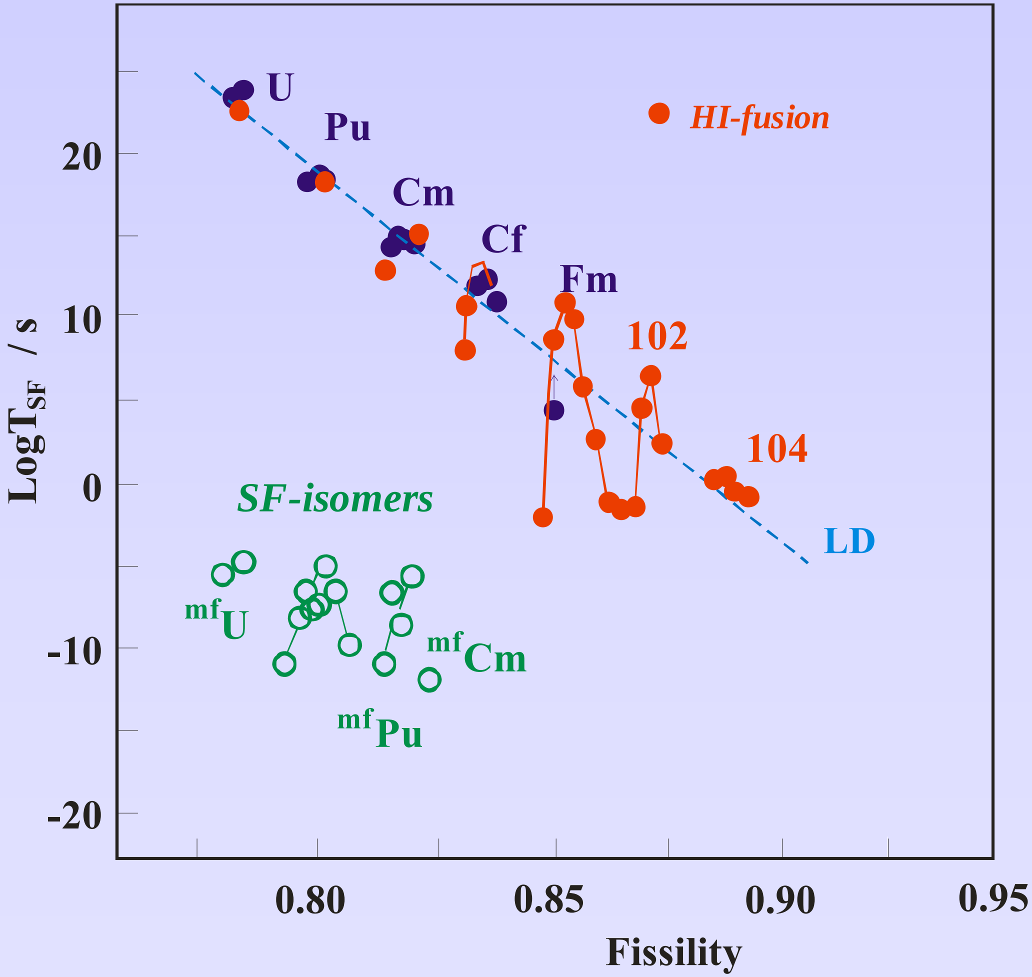
Otto Hahn Lise Meitner

$${}^{238}_{92}\mathrm{U} + n \longrightarrow {}^{239}_{92}\mathrm{U}^* \longrightarrow {}^{239}_{93}\mathrm{Nn} + e^- + \bar{\nu}$$



1938: discovery of nuclear fission and formulation of the liquid drop model

Spontaneous fission half-lives of actinides



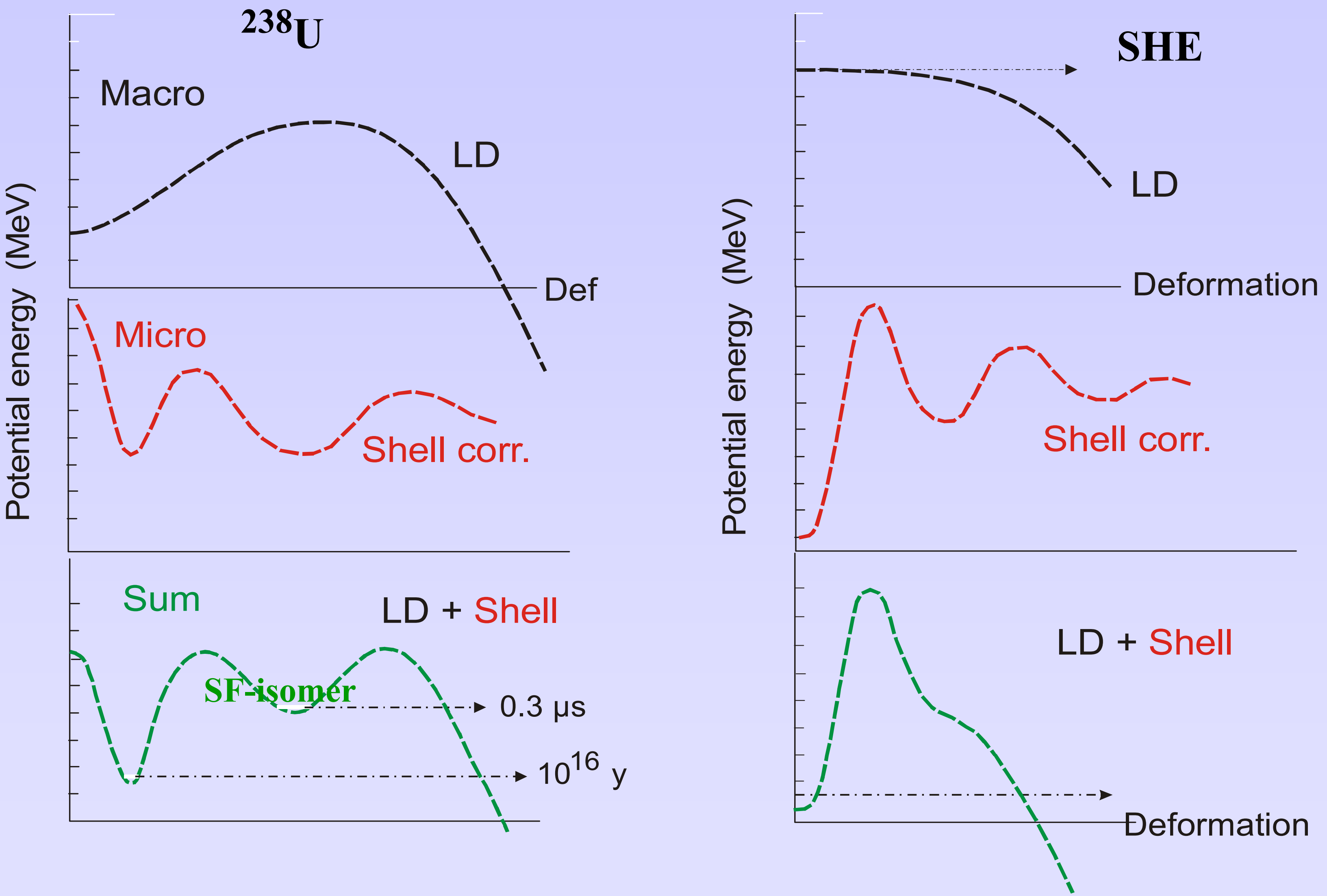
Prehistory

- **1966: A. Sobiczewski, F.A. Gareev, B.N. Kalinkin: next "magic numbers" are Z=114, N=184;**
- **1966: W.D. Myers, W.J. Swiatecki: next "magic numbers" are Z=126, N=184**
- **1966: V.M. Strutinsky; "shell correction" method**
- **1967: H.B. Meldner: next "magic numbers" are Z=114, N=184**

Accuracy of predictions:

- **Spontaneous fission half-life: $T_{1/2} * 10^{\pm 10}$!!**
- **α-decay: $T_{1/2} * 10^{\pm 10}$!!**

Microscopic corrections to the macroscopic nuclear deformation energy



Search for SHE in Nature

- Search for SHE in terrestrial matter
- Search for SHE in meteorites
- Search for SHE in cosmic rays
- Investigation of isotopic anomalies

20 years → Void result,

but many new high sensitive detection methods were developed

Synthesis of SHE at accelerators

- 1971; Orsay, France; $^{232}Th + ^{82}Kr \rightarrow ^{310}126 + 4n$; $\sigma_{4n} < 0.5$ mb !!!
- 1971-1975; Dubna, SU; deep inelastic or fission reactions of ^{76}Ge, $^{136}Xe + ^{238}U$
- 1975; Dubna, SU; ^{48}Ca + actinides

Shell corrections

Proton shell:

114 or/and 126, 120 ?

Neutron shell:

172 or/and 184 ?

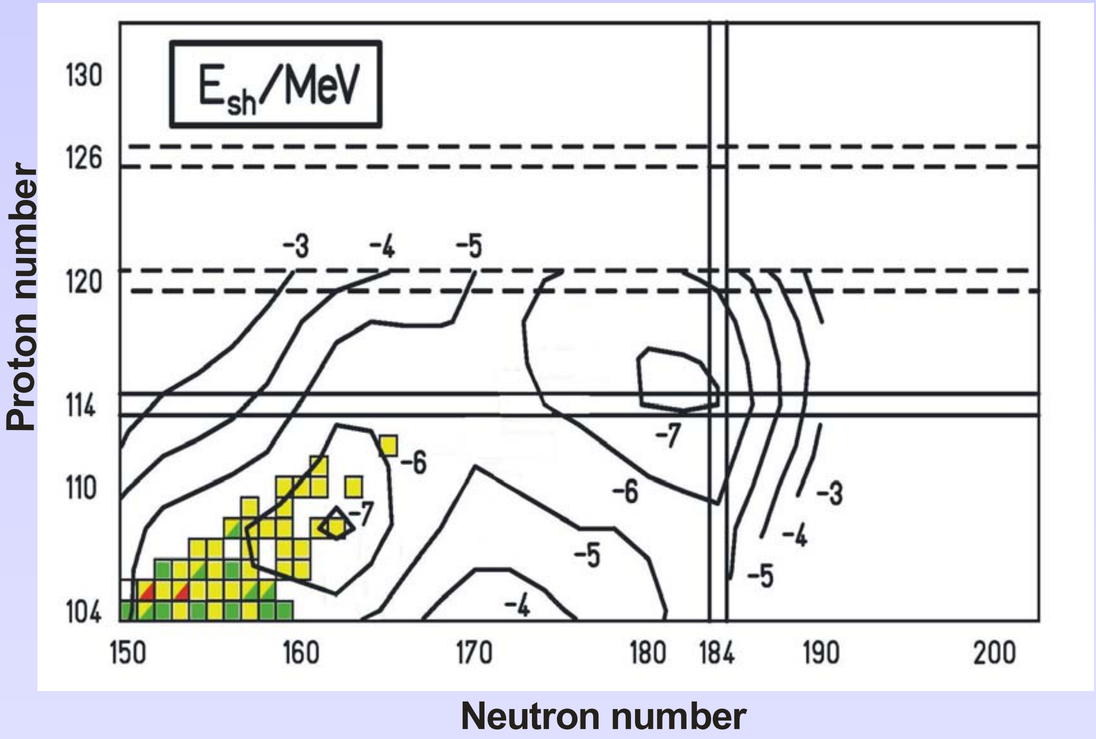
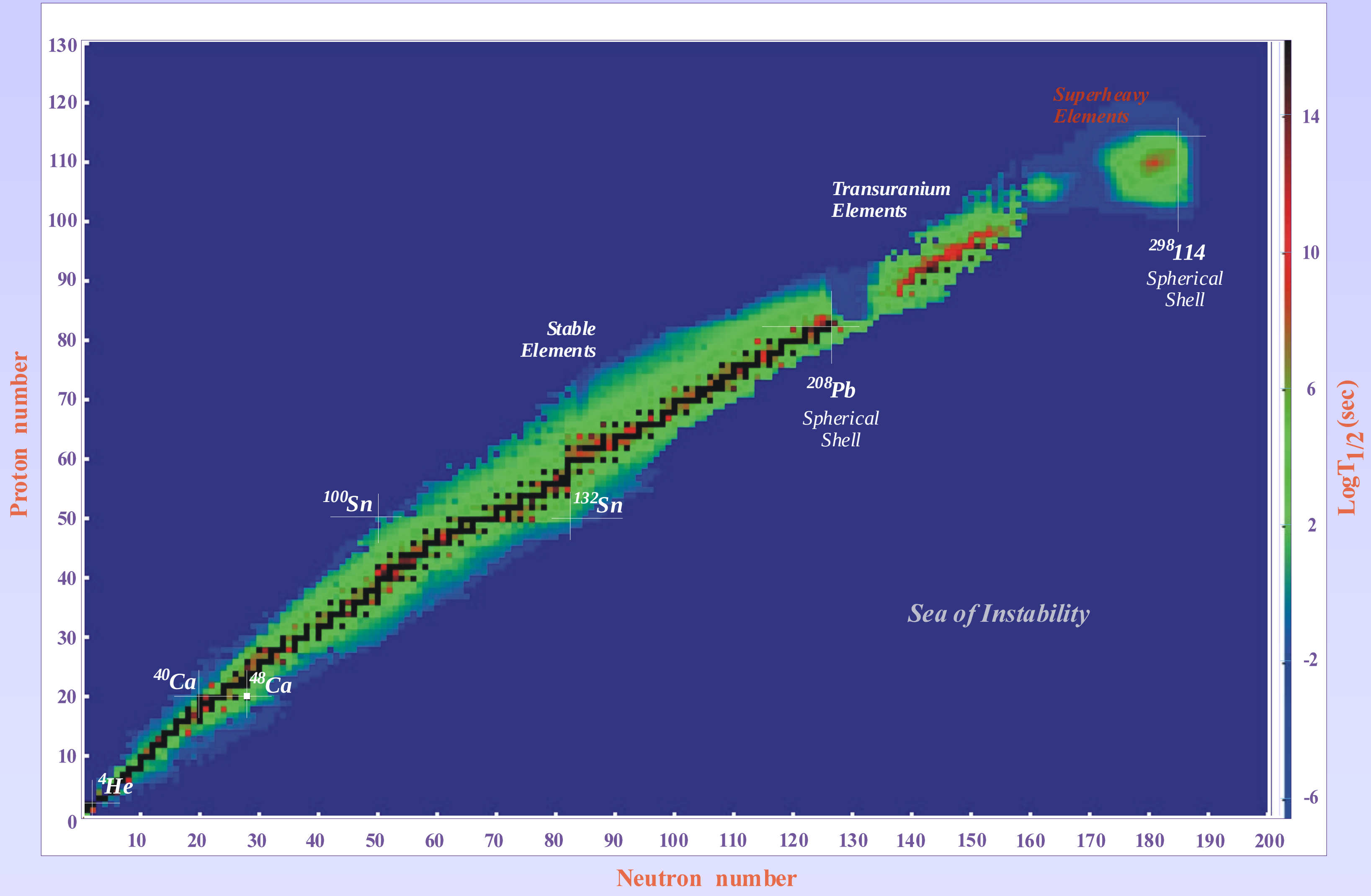
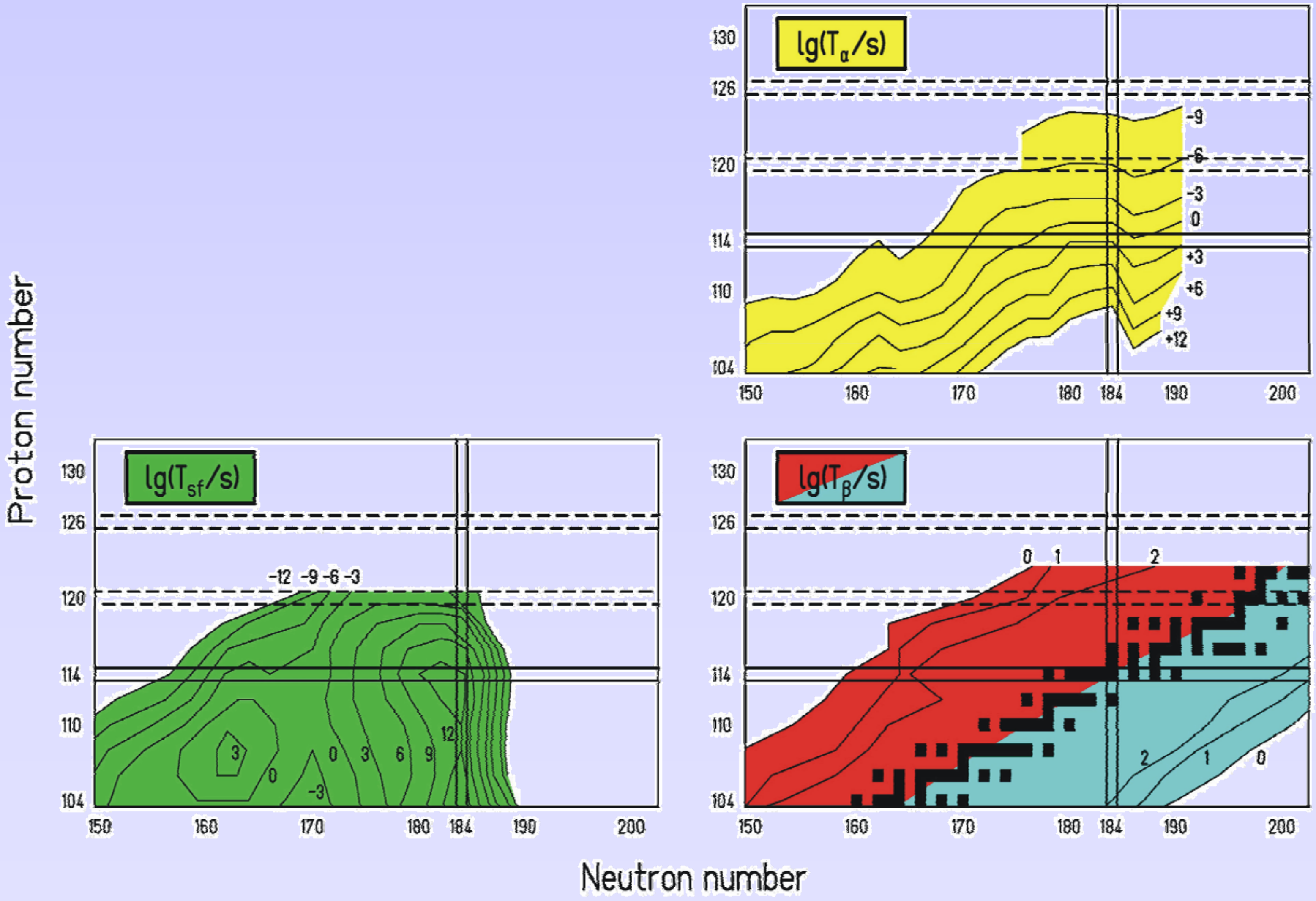


Chart of the Nuclides

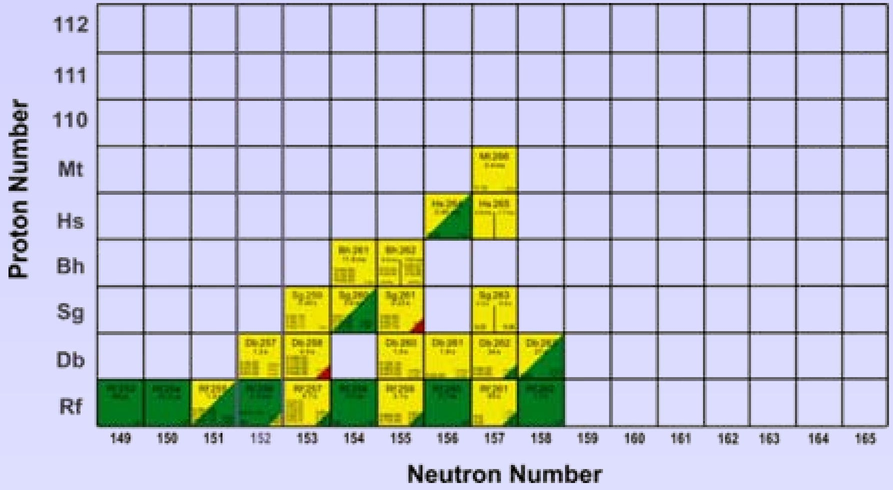


Partial decay half-lives

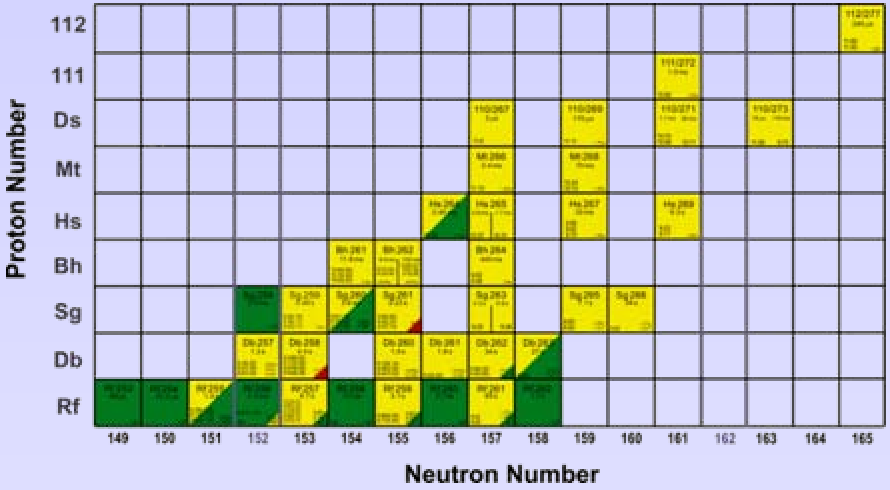


Charts of transactinide nuclides

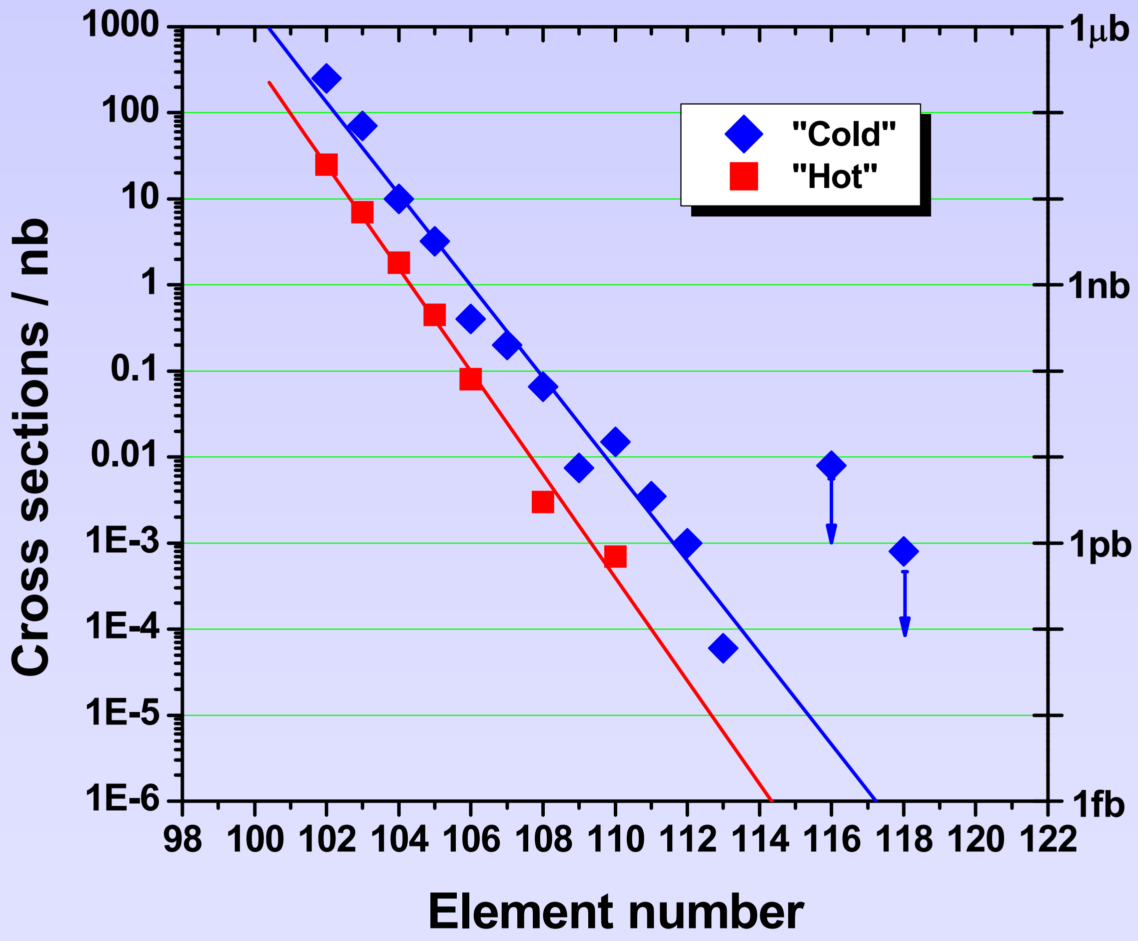
1984



1996



Cross-sections of Hot (actinide targets) and Cold (Pb or Bi targets) fusion reactions



Experimental conditions

Consumption
of the ^{48}Ca (68%) - 0.5 mg/h

beam
intensity - $5 \cdot 10^{12}$/s

beam time - 2000 h/y

Isotopes:

$^{233,238}U$, $^{242,244}Pu$, ^{243}Am, $^{245,248}Cm$, ^{249}Cf + ^{48}Ca → Z = 112 - 118

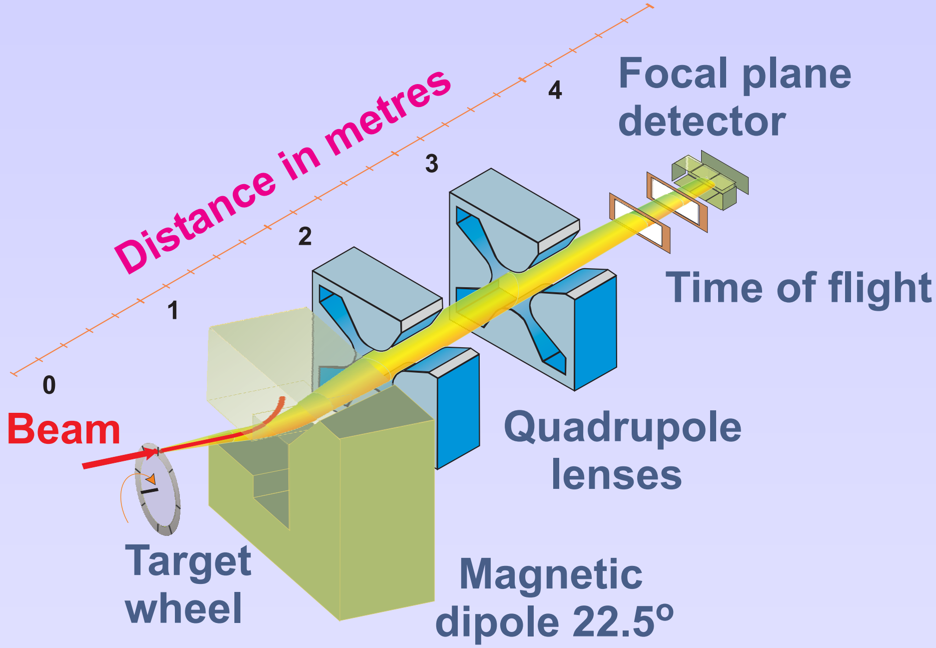
isotope enrichment - 98-99%
S2-separator
(Sarov)

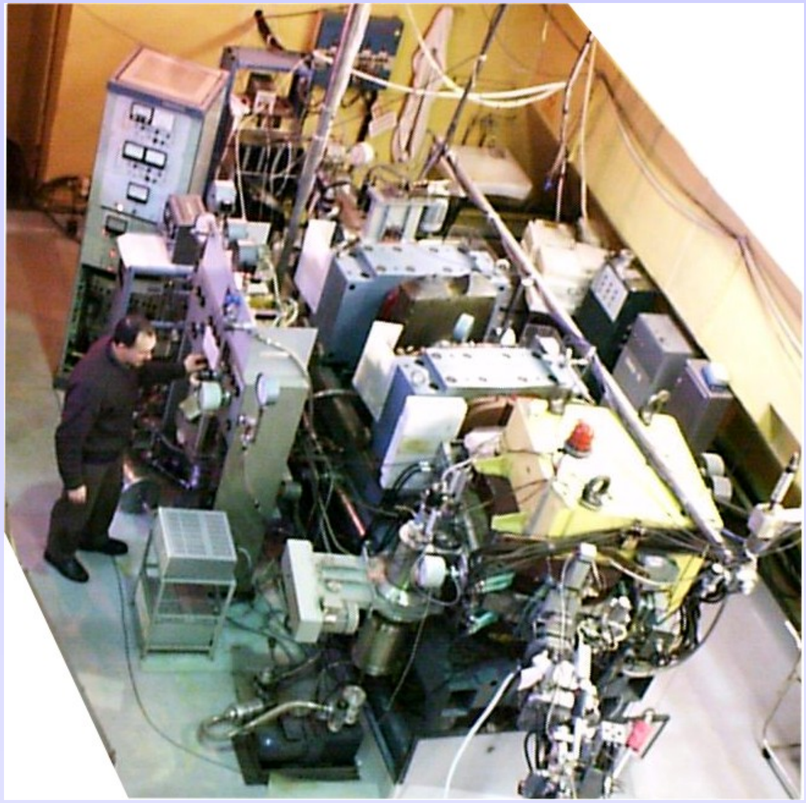
technology of the
target preparation - 0.3 (2.0) mg/cm^2

Separation of super heavy nuclei
DGFRS,
VASSILISSA,
chemistry
and
detection their radioactive decay

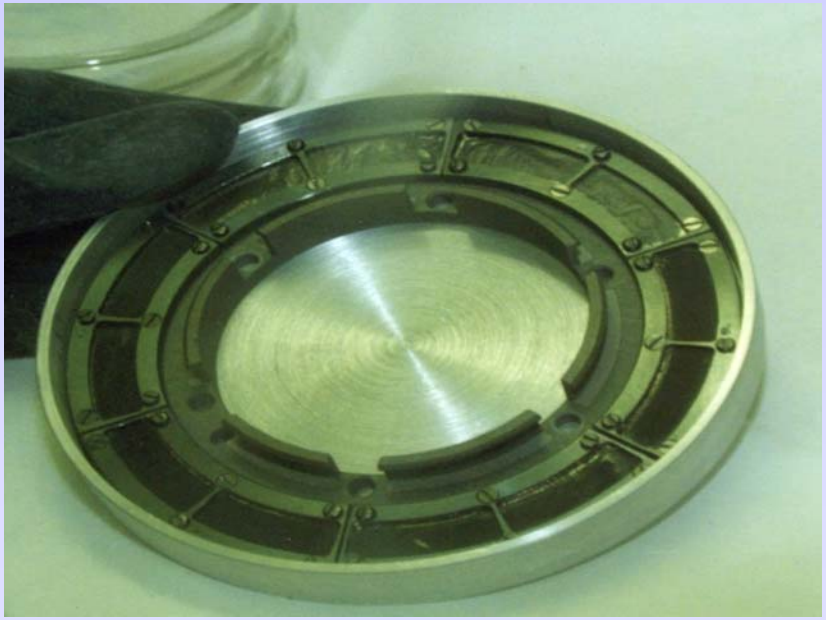
FLNR U400 cyclotron

Dubna Gas Filled Recoil Separator





^{249}Cf - target

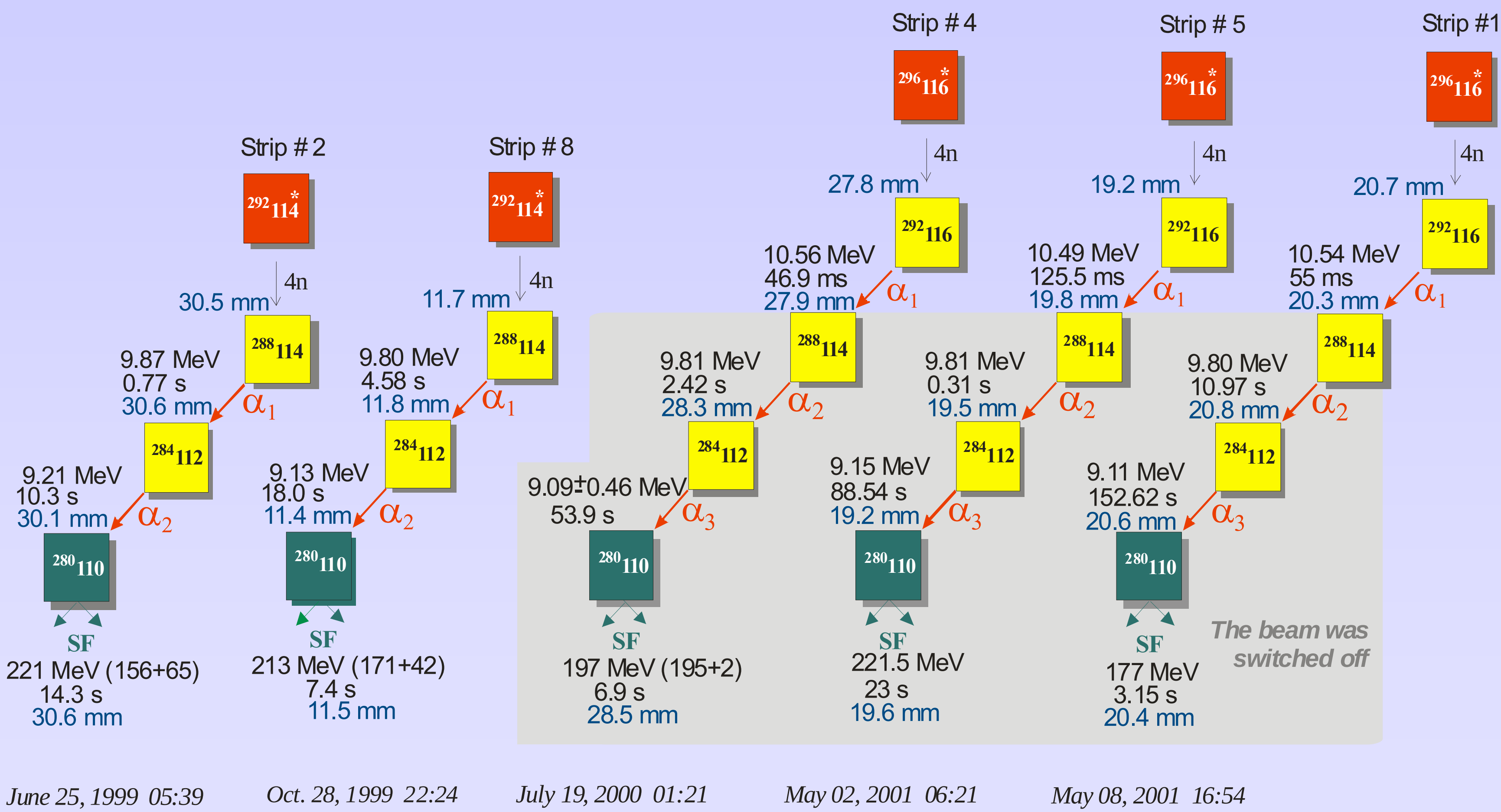


$^{244}Pu + {}^{48}Ca \rightarrow {}^{292}114^{*}$

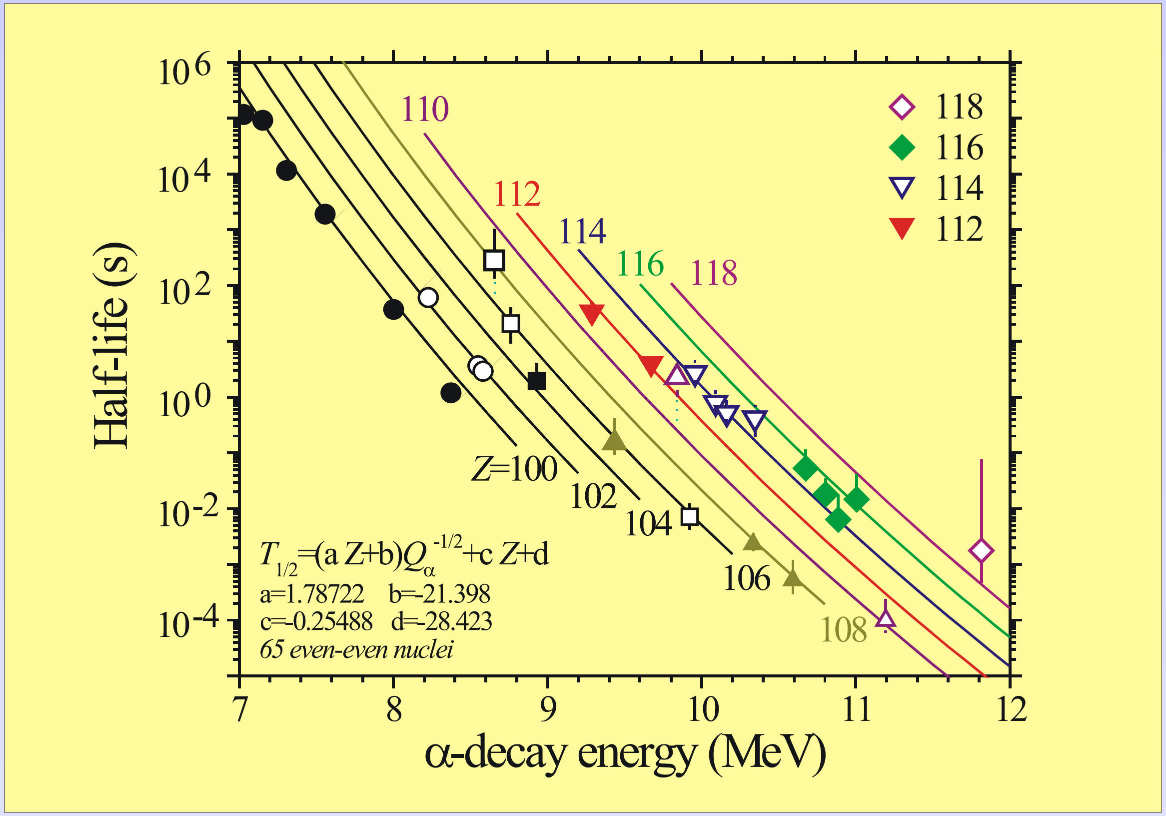
Total beam dose: $1.5 \cdot 10^{19}$

$^{248}Cm + {}^{48}Ca \rightarrow {}^{296}116^{*}$

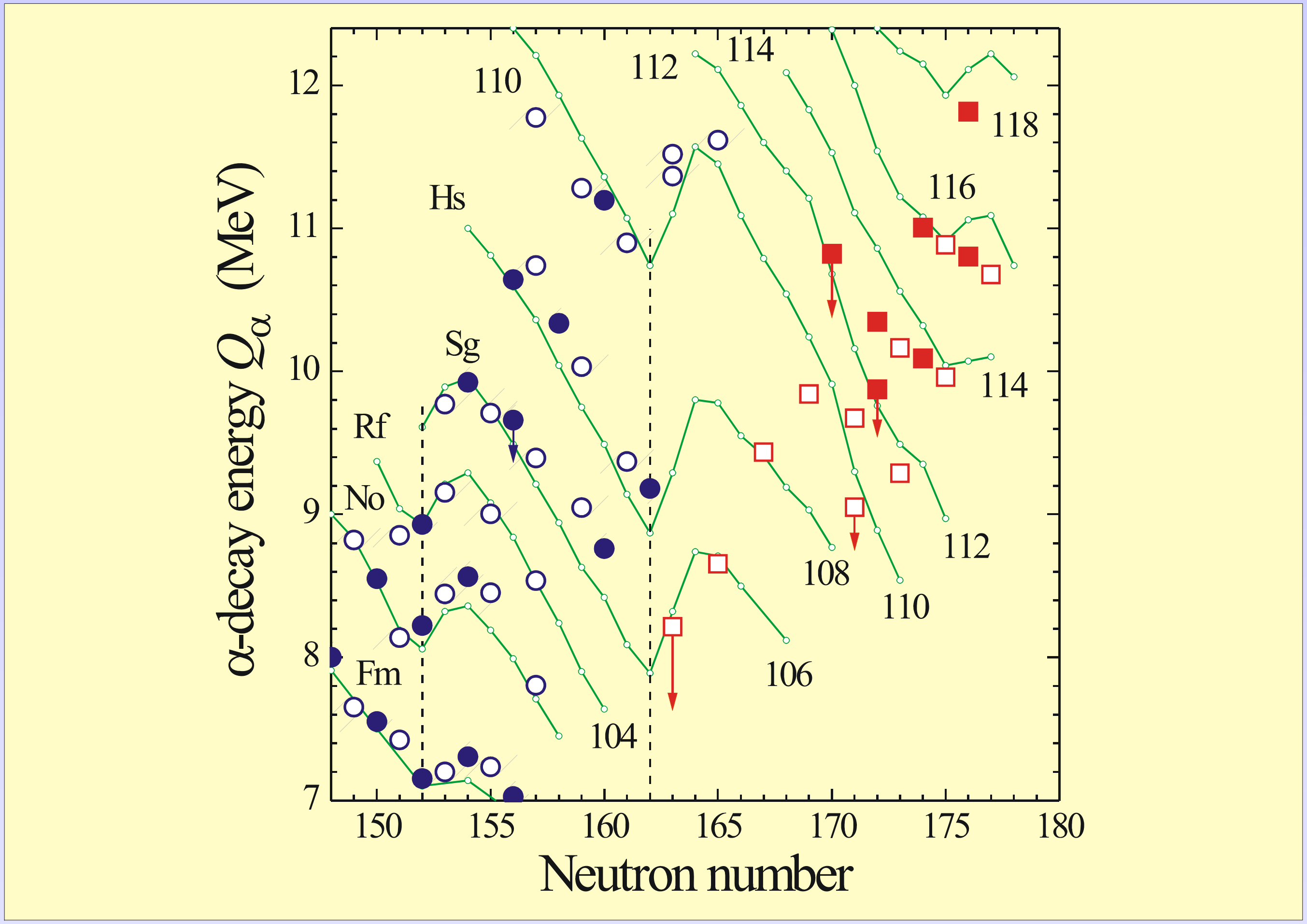
Total beam dose: $2.3 \cdot 10^{19}$



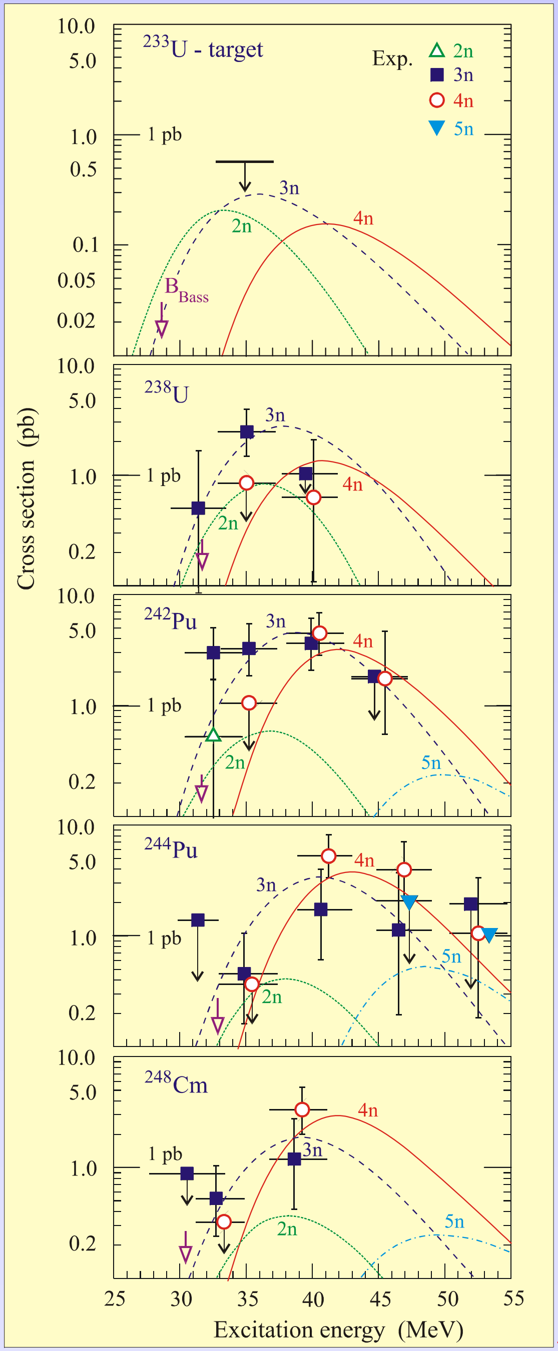
Q_α - $T_{1/2\alpha}$ obey the rule of Geiger – Nuttal

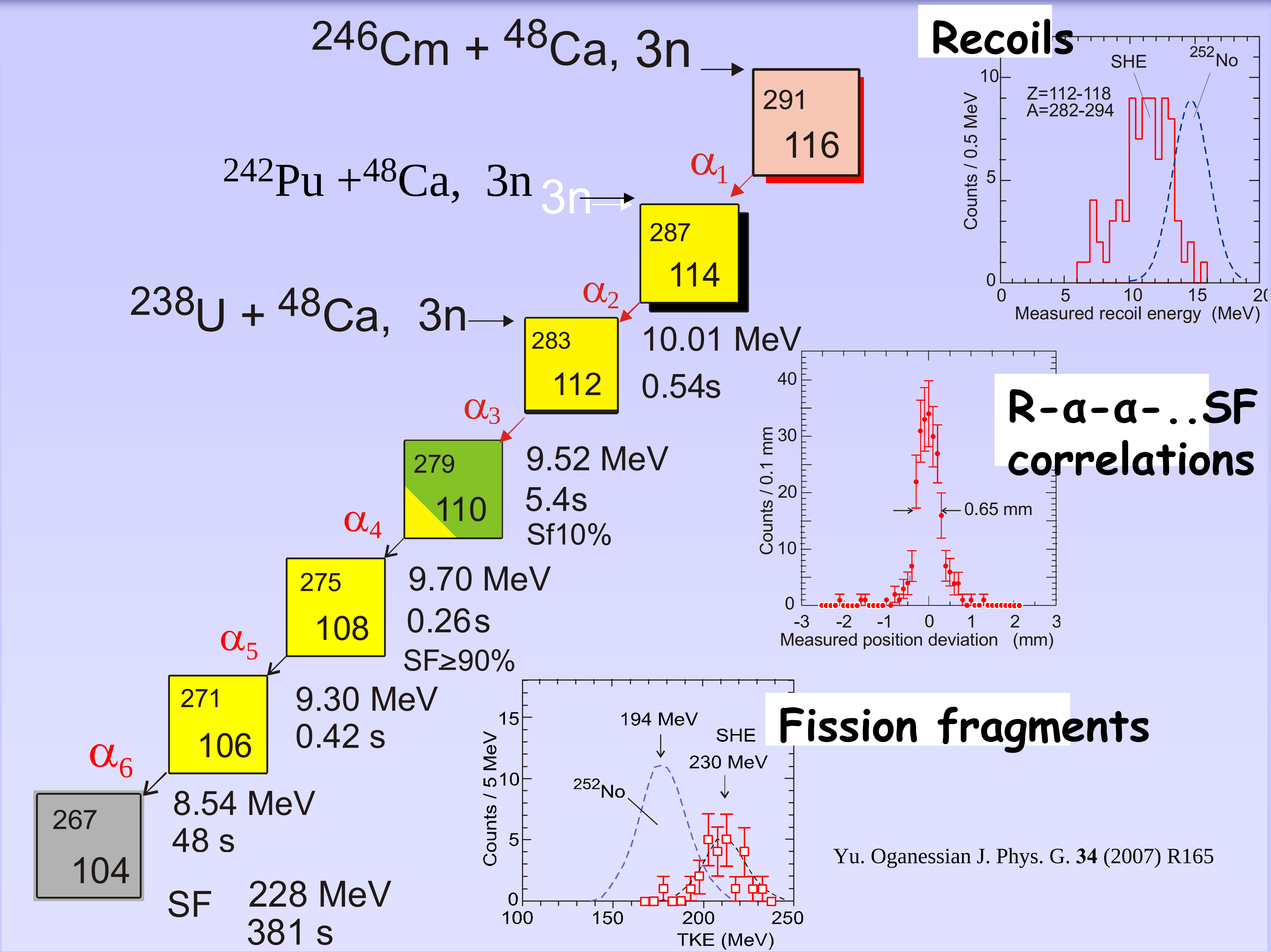


Experimental and Calculated Values of Q_α



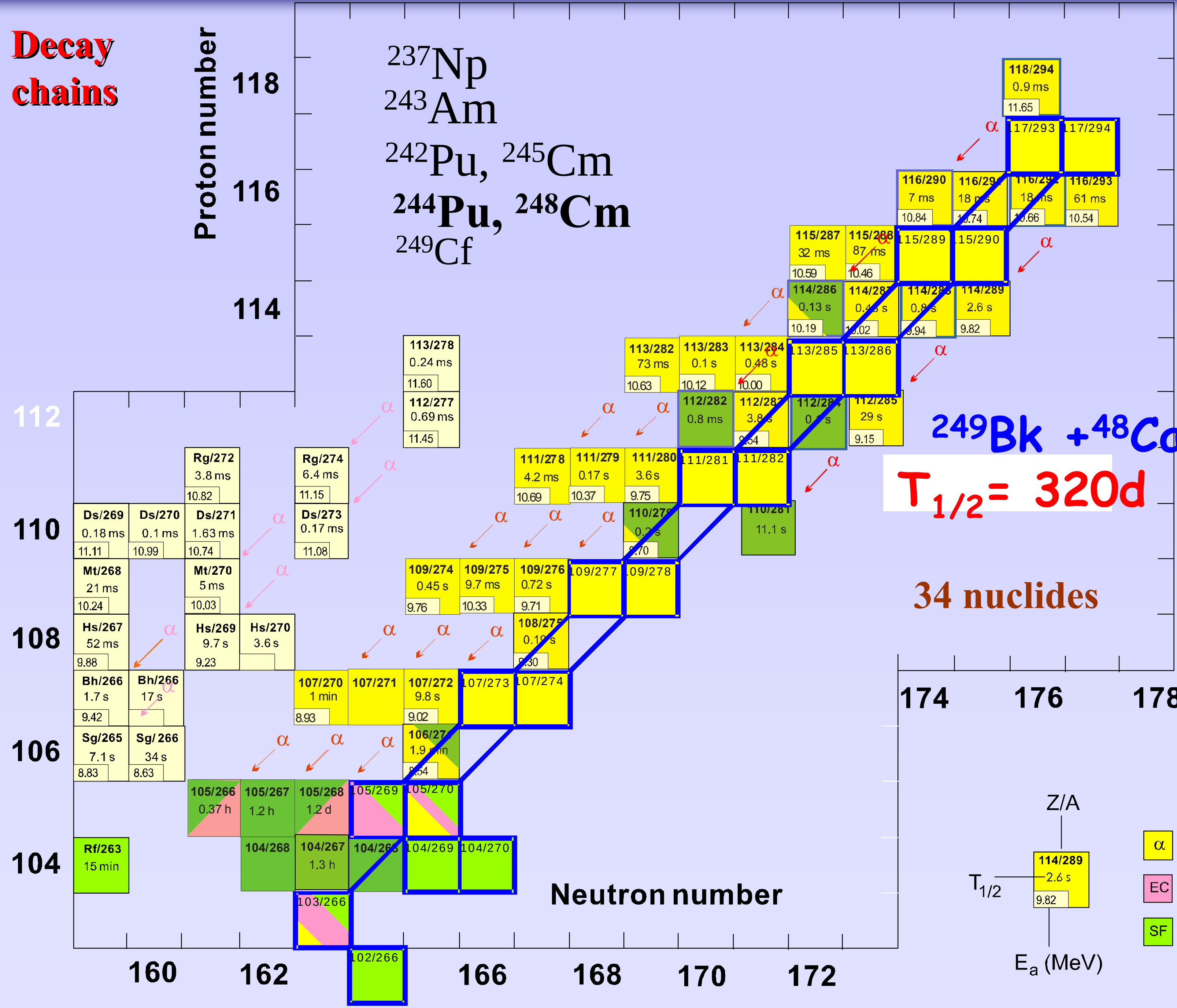
Excitation functions of the $^{48}Ca+^{238}U, ^{242}Pu, ^{244}Pu, ^{248}Cm$ +xn reactions





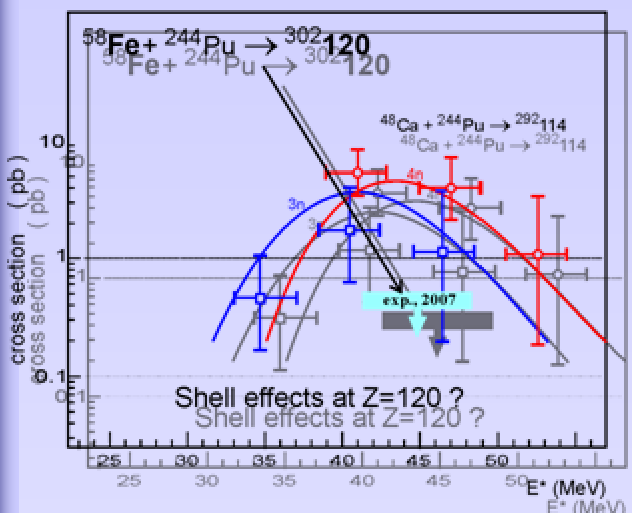
246Cm + 48Ca, 3n
242Pu +48Ca, 3n
3n
238U + 48Ca, 3n
291
116
α1
287
114
α2
283
112
10.01 MeV
0.54s
α3
279
110
9.52 MeV
5.4s
Sf10%
α4
275
108
9.70 MeV
0.26s
SF≥90%
α5
271
106
9.30 MeV
0.42 s
α6
267
104
8.54 MeV
48 s
SF
228 MeV
381 s
Recoils
SHE
252No
Z=112-118
A=282-294
Counts / 0.5 MeV
Measured recoil energy (MeV)
R-α-α-..SF
correlations
0.65 mm
Counts / 0.1 mm
Measured position deviation (mm)
Fission fragments
194 MeV
SHE
230 MeV
252No
Counts / 5 MeV
TKE (MeV)
Yu. Oganessian J. Phys. G. 34 (2007) R165

Decay chains

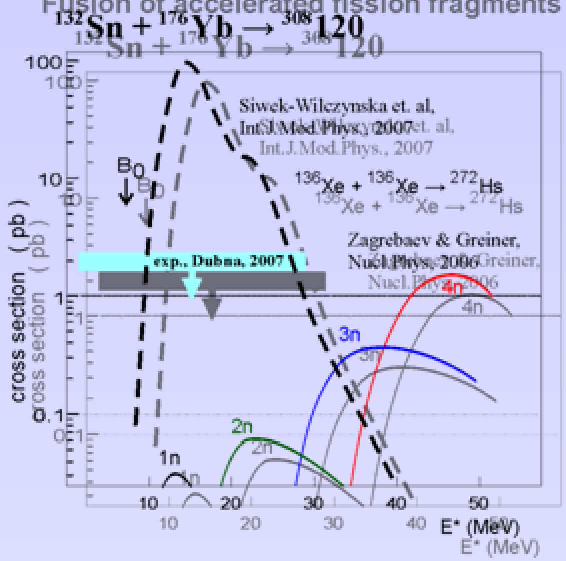


Alternative methods for synthesis of superheavies

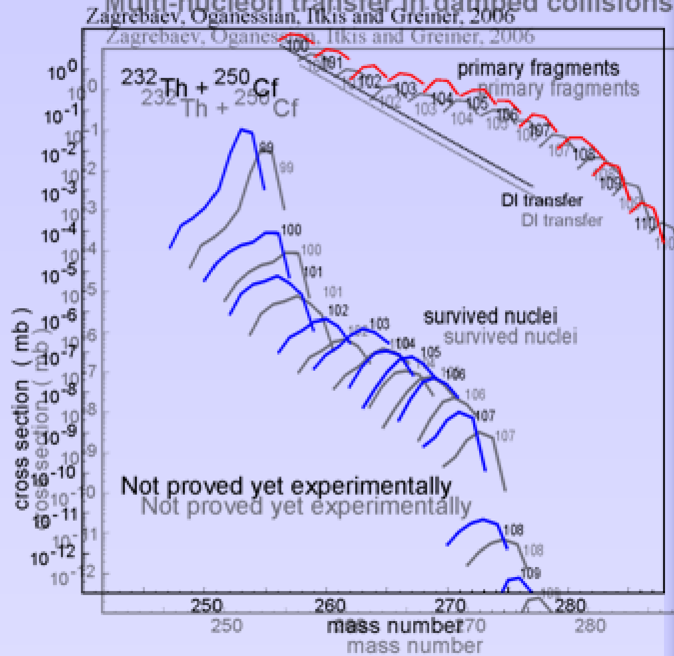
Heavier that ^{48}Ca projectiles



Fusion of accelerated fission fragments



Multi-nucleon transfer in damped collisions



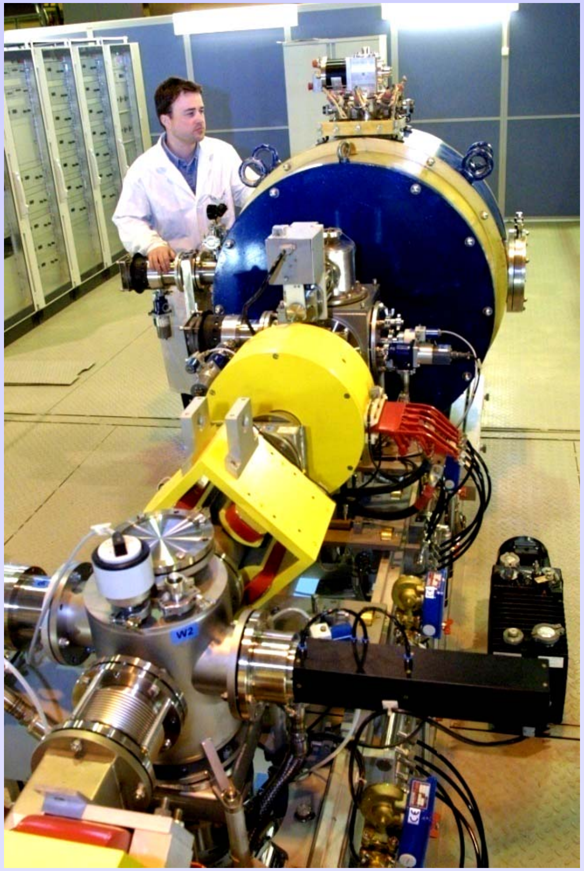
Methods of identification:

- generic decay links;
- cross-bombardments;
- on-line post separator;
- quasi-on-line mass analyzer;
- calorimetric detectors;
- Ge-γ- detectors;
- ion traps;
- radiochemical methods.

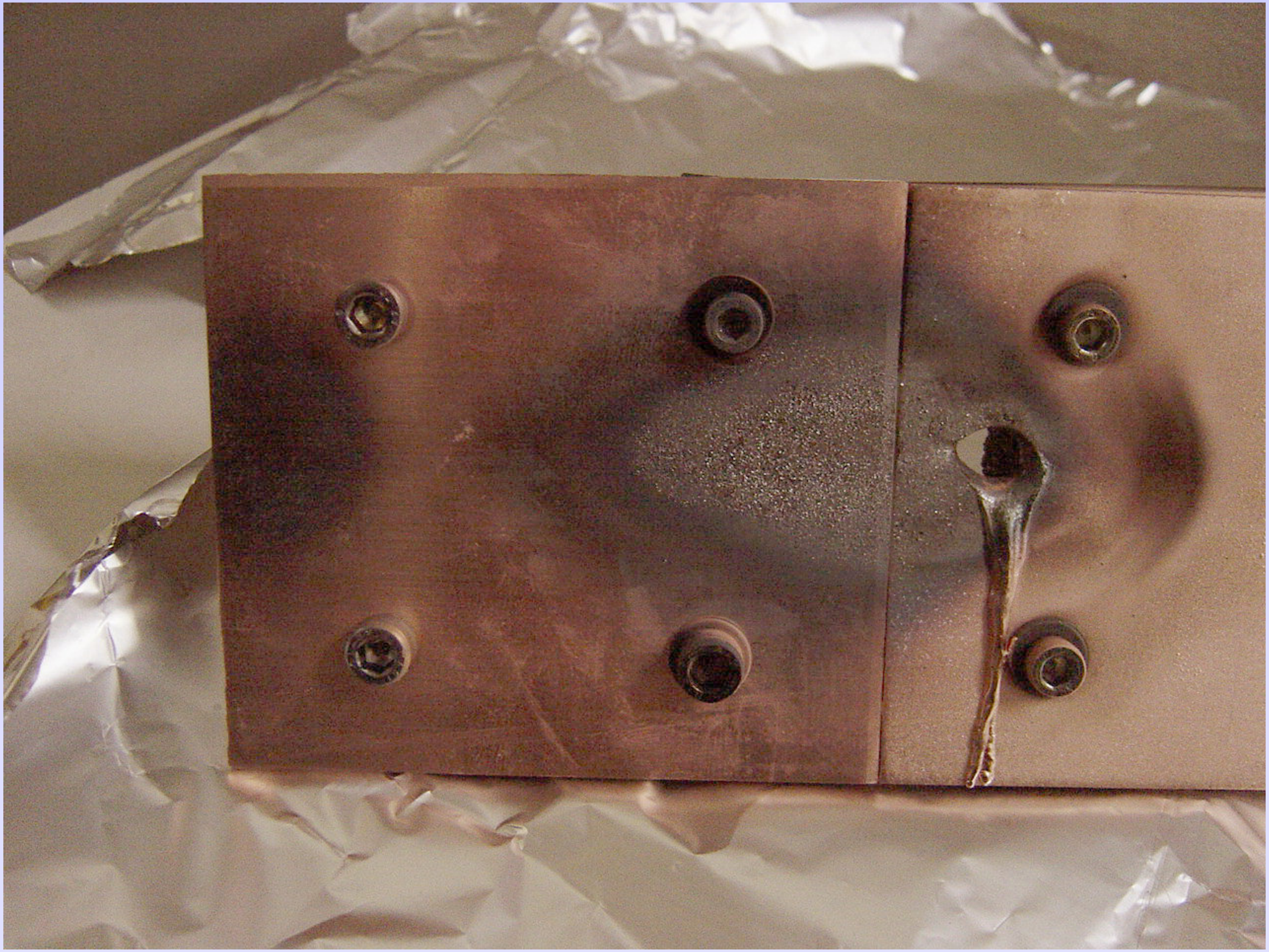
We need higher production rates!

Accelerator improvements

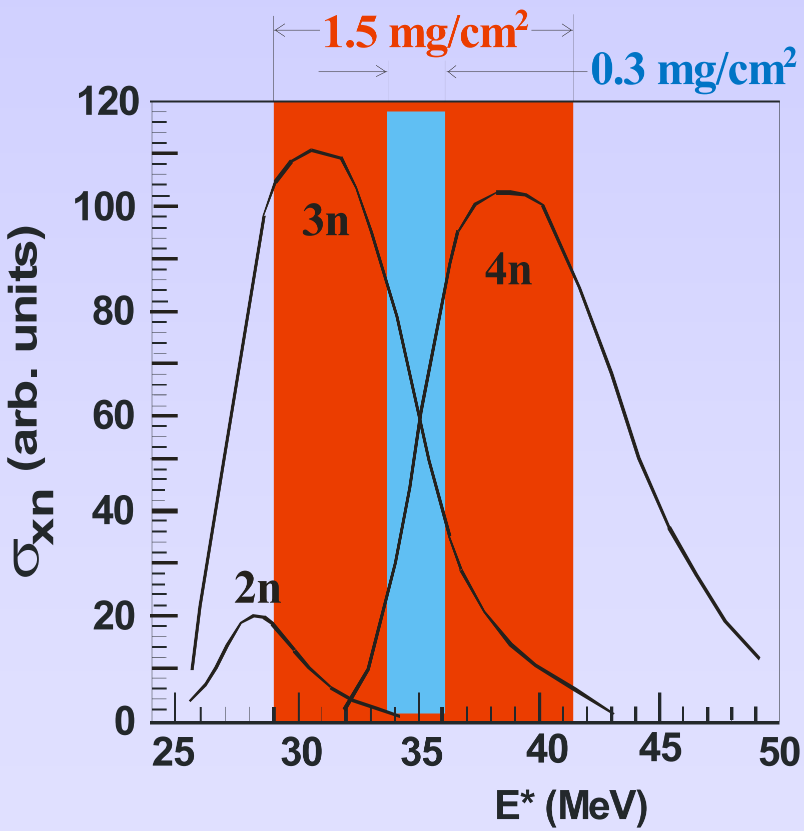
- Modernization of the magnetic system of U400
- Modernization of power supplies
- Introduction of 18-GHz superconducting ECR-ion source



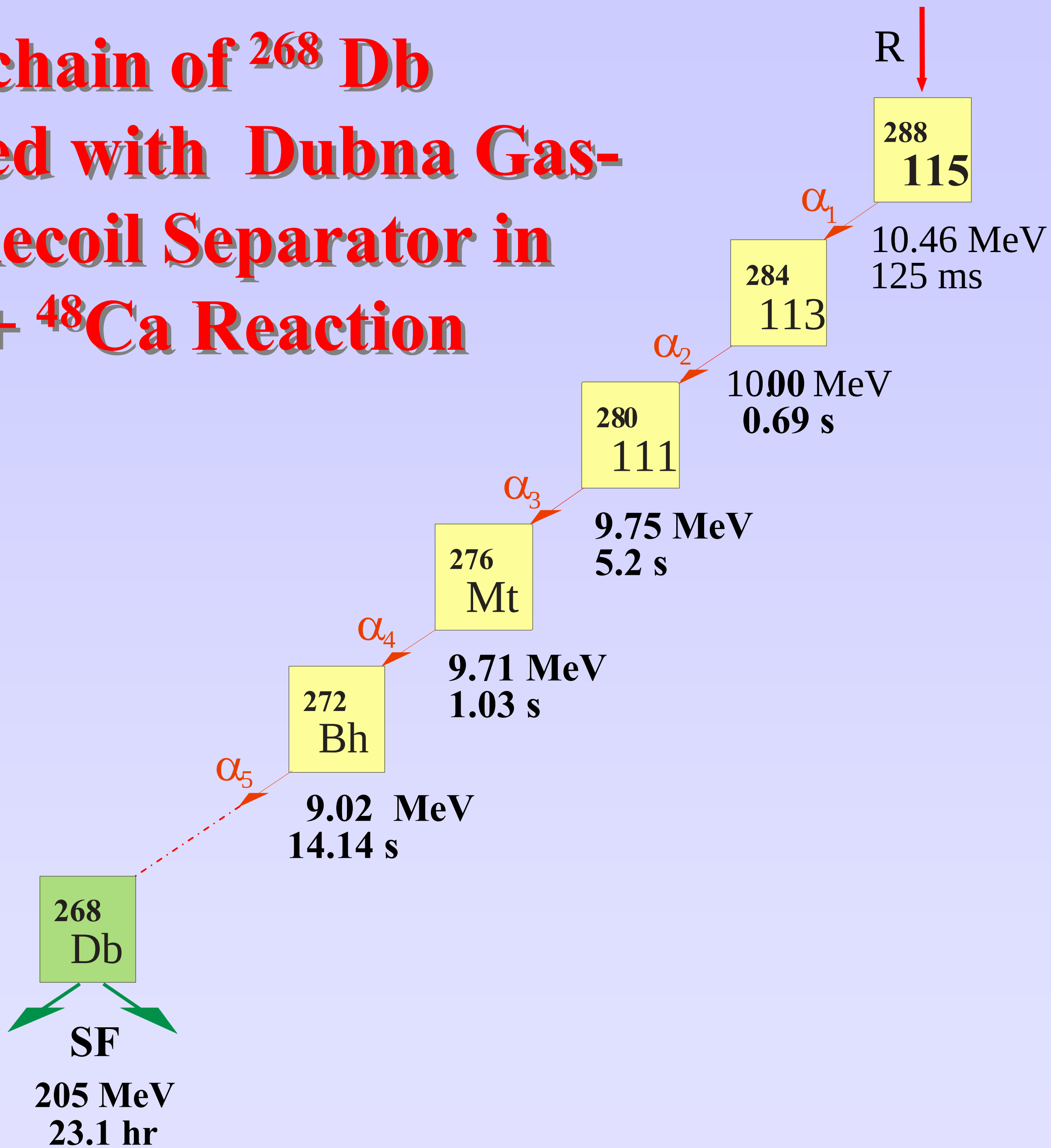
Molten Beam Stop



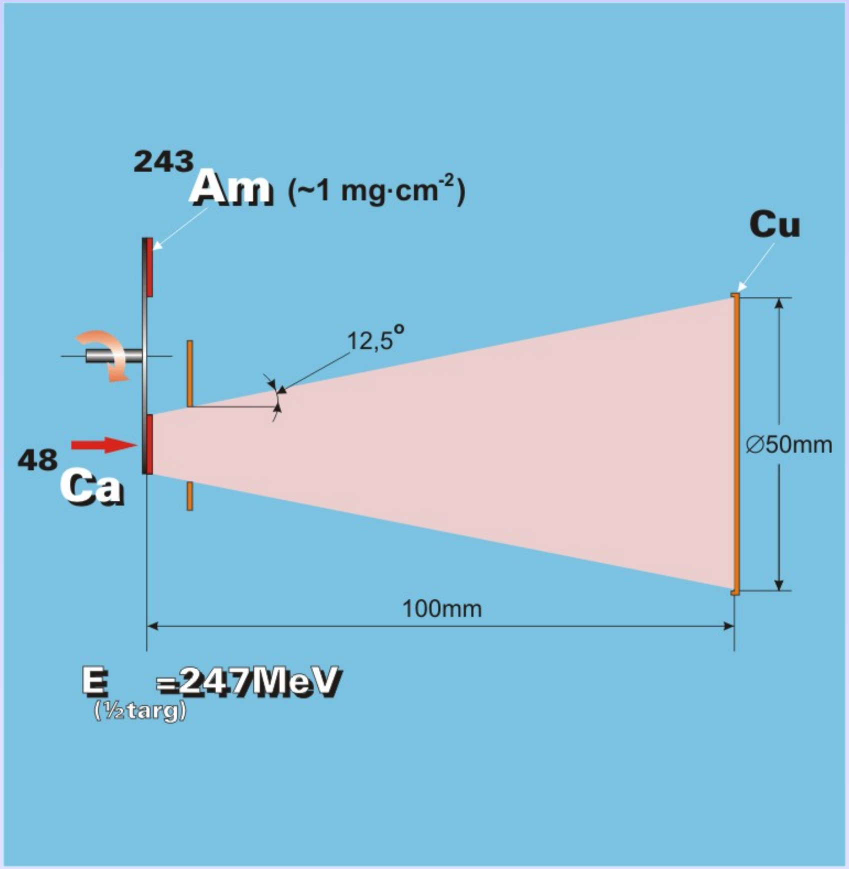
Chemistry and masspectrometry



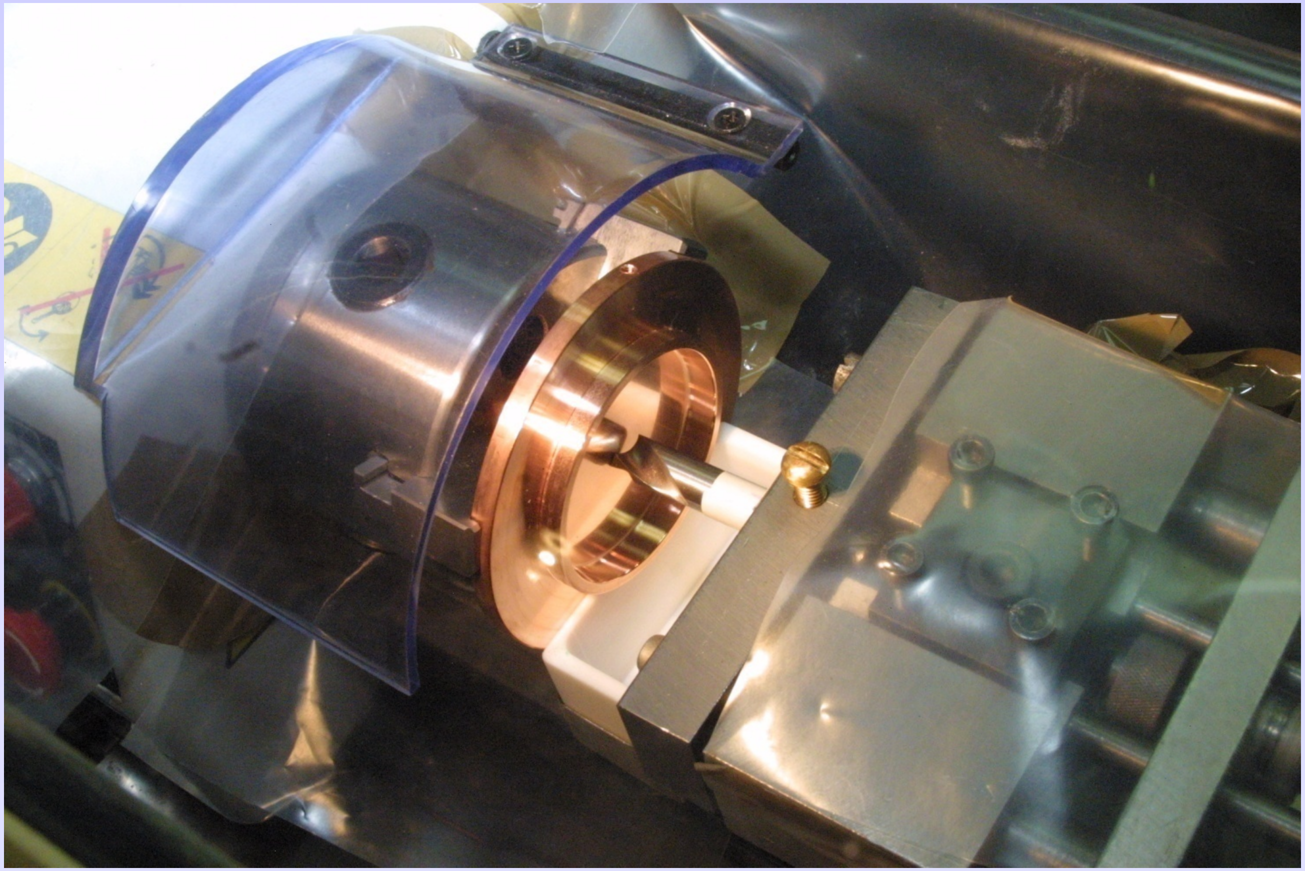
Decay chain of ^{268}Db observed with Dubna Gas-filled Recoil Separator in ^{243}Am + ^{48}Ca Reaction



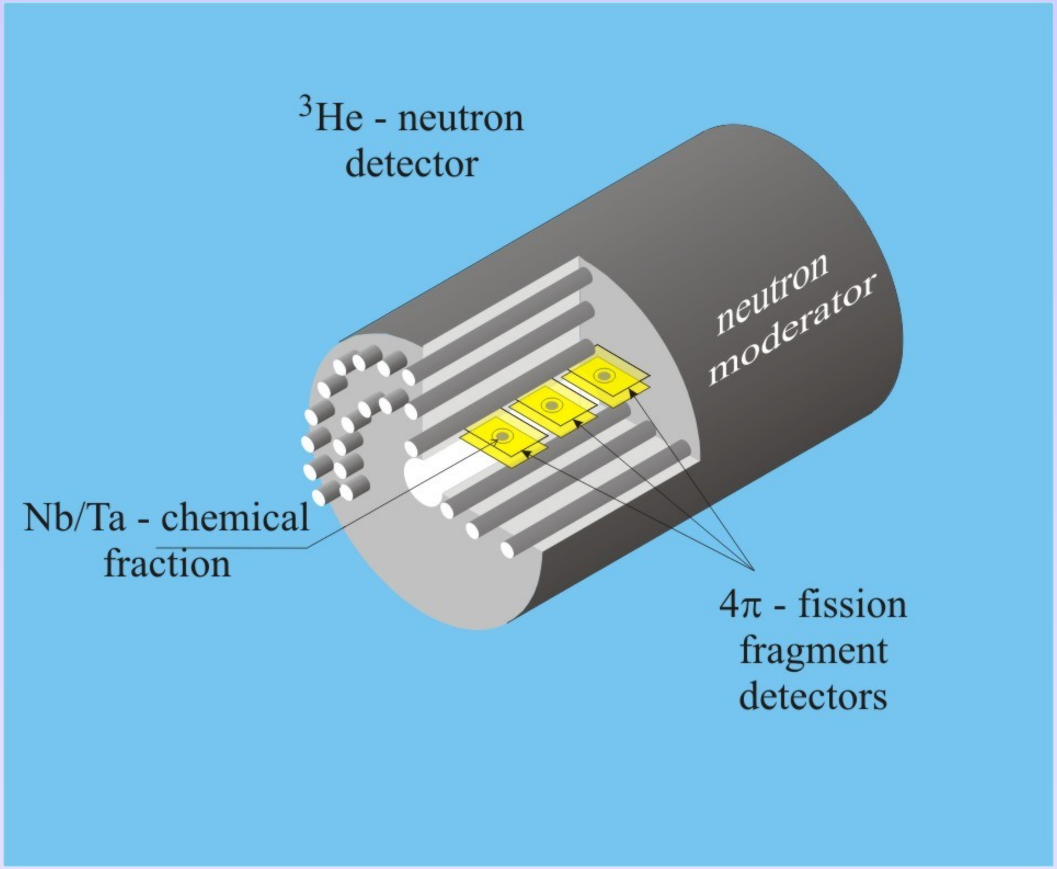
Irradiation of ^{243}Am-target with ^{48}Ca-ions



Taking off thin layer of Cu-catcher (100÷150 mg of Cu)

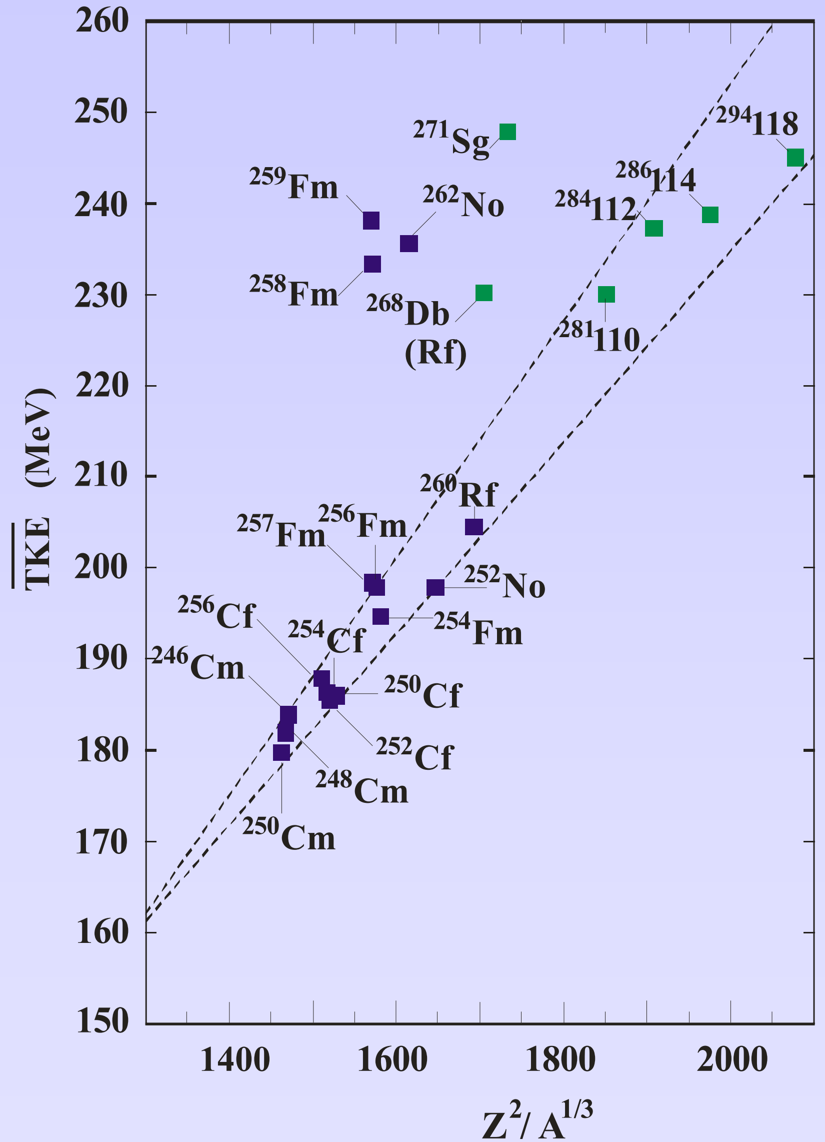


Detection system

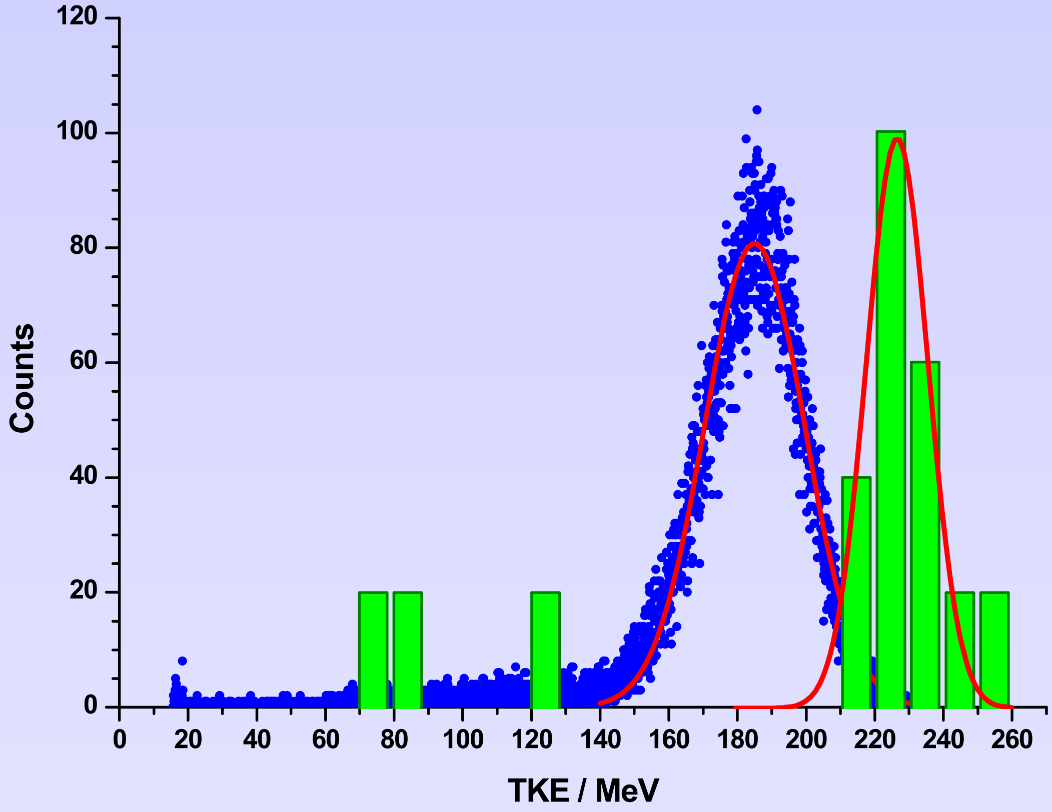


Systematic of SF TKE

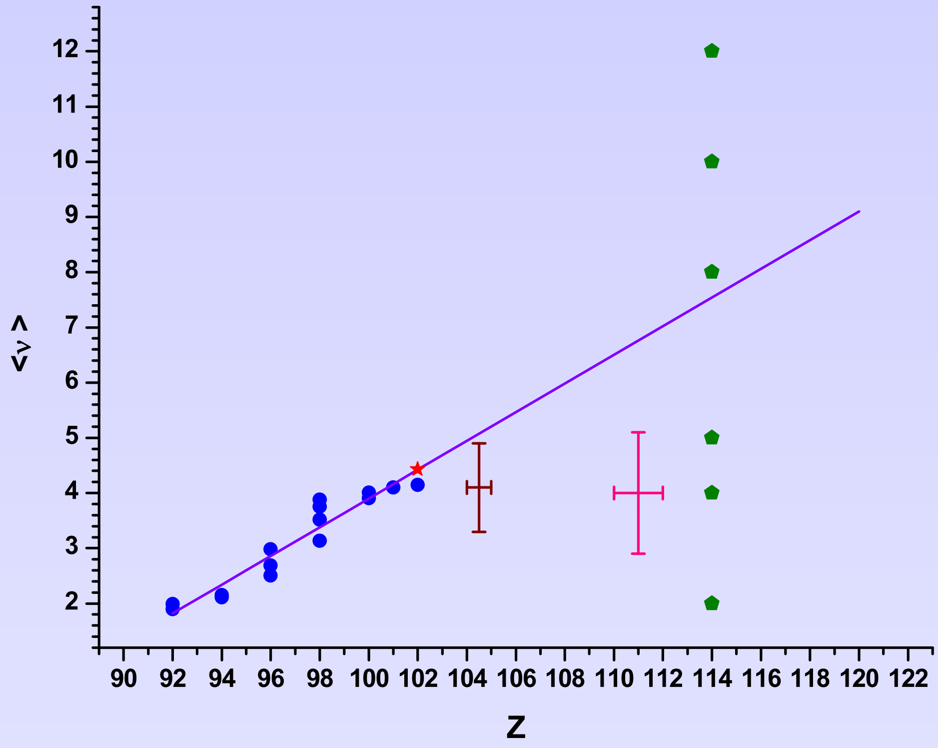
TKE > 200 MeV →
Z ≥ 106



Total Kinetic Energy distributions of ^{252}Cf and ^{268}Db



Average numbers of prompt neutrons emitted in spontaneous fission



Los Alamos National Laboratory's Chemistry Division Presents a

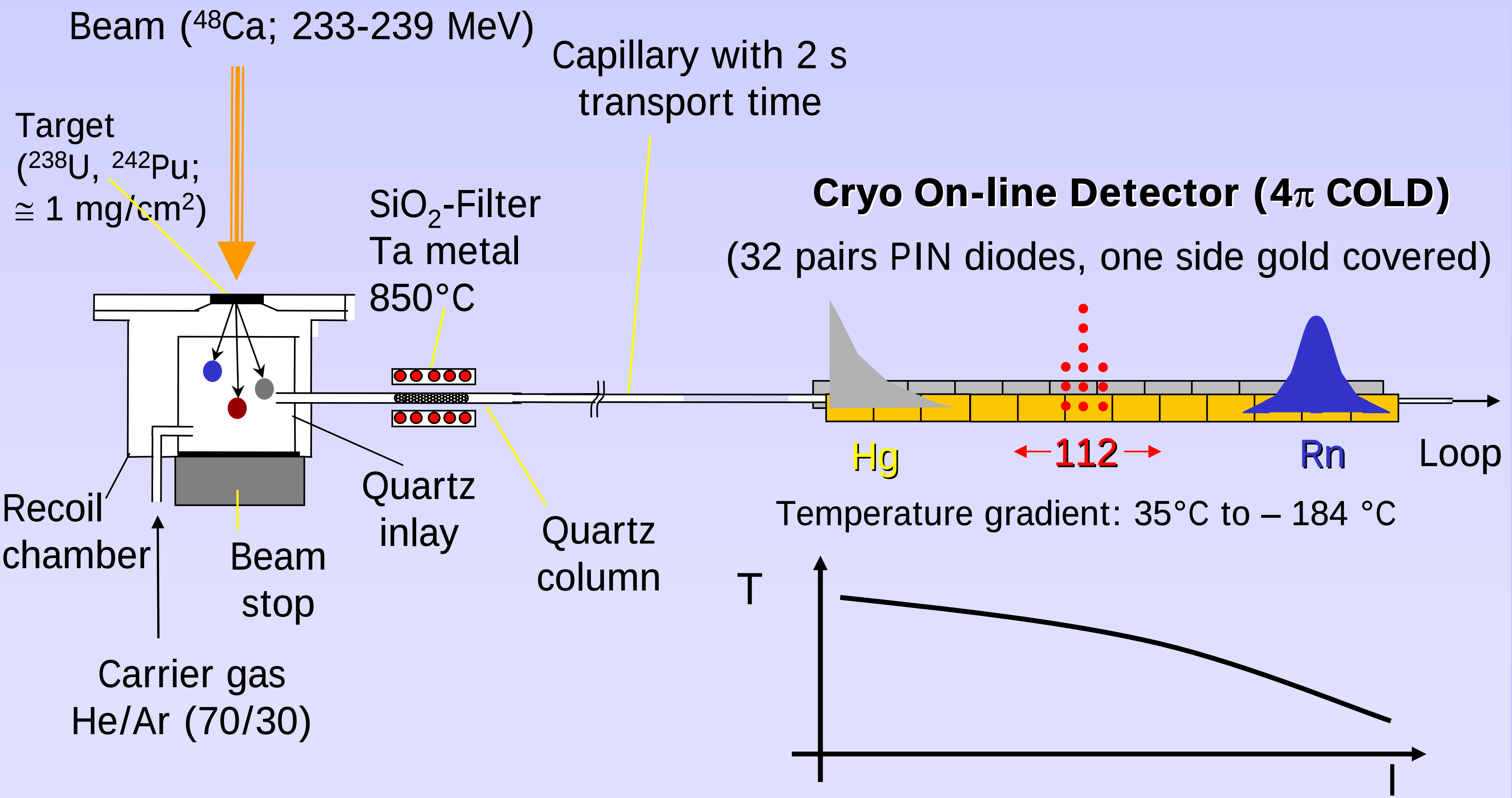
Periodic Table of the Elements

Group**

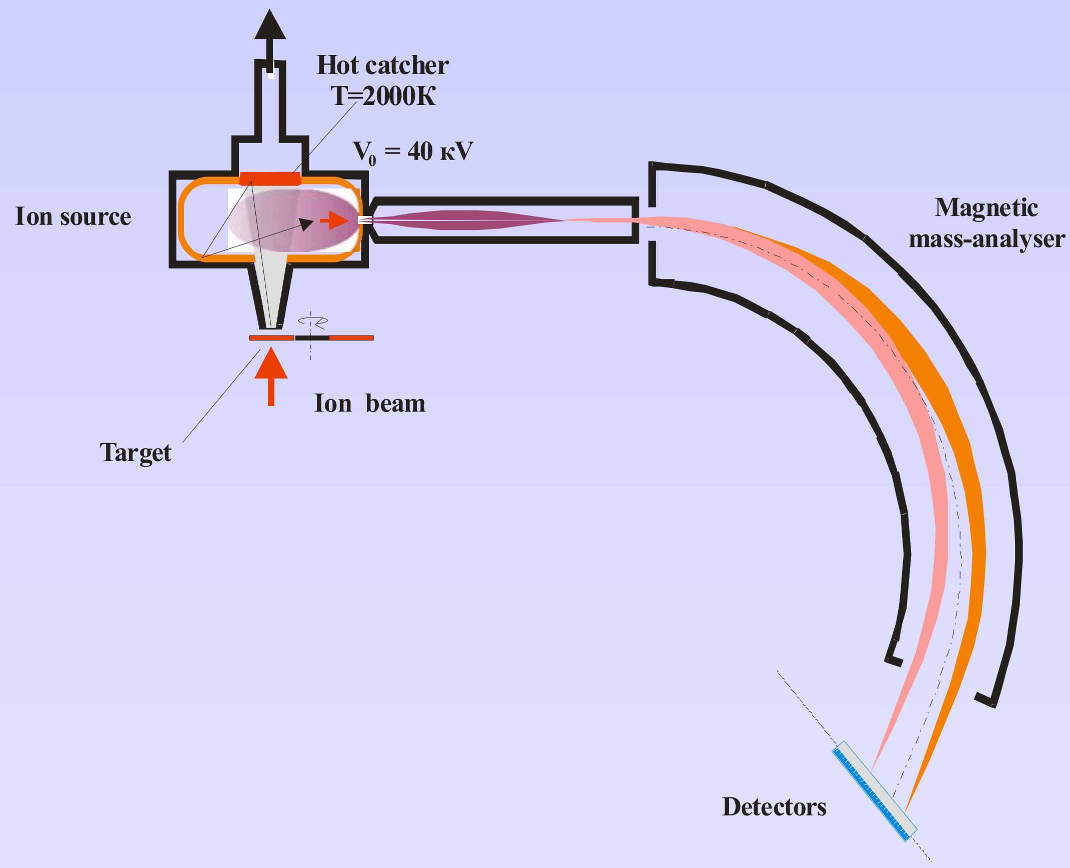
Period	1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 ------- VIII ------- 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac~ (227)	104 Rf (257)	105 Db (260)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 --- 0	111 --- 0	112 --- 0		114 --- 0		116 --- 0		118 --- 0

Series														
Lanthanide Series*	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (147)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
Actinide Series~	90 Th 232.0	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)

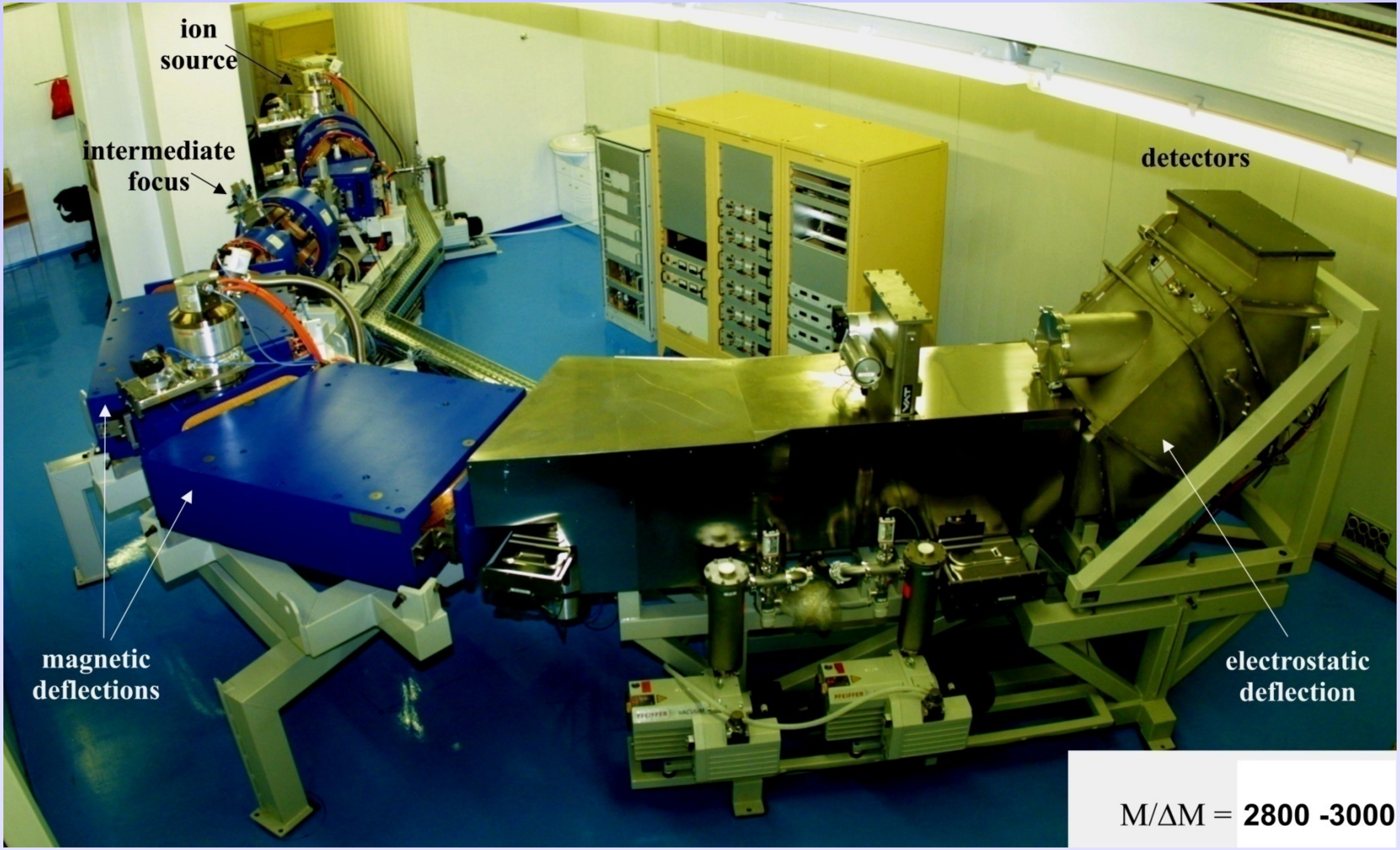
Chemistry of the elements 112 & 114



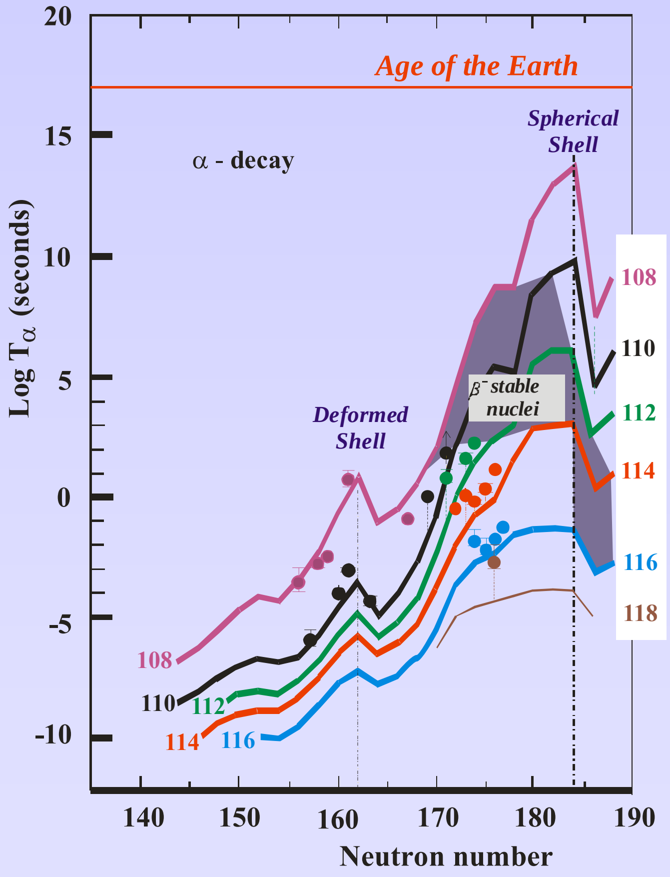
Mass Analyzer of Super Heavy Atoms
Δm/m=1000 (project)



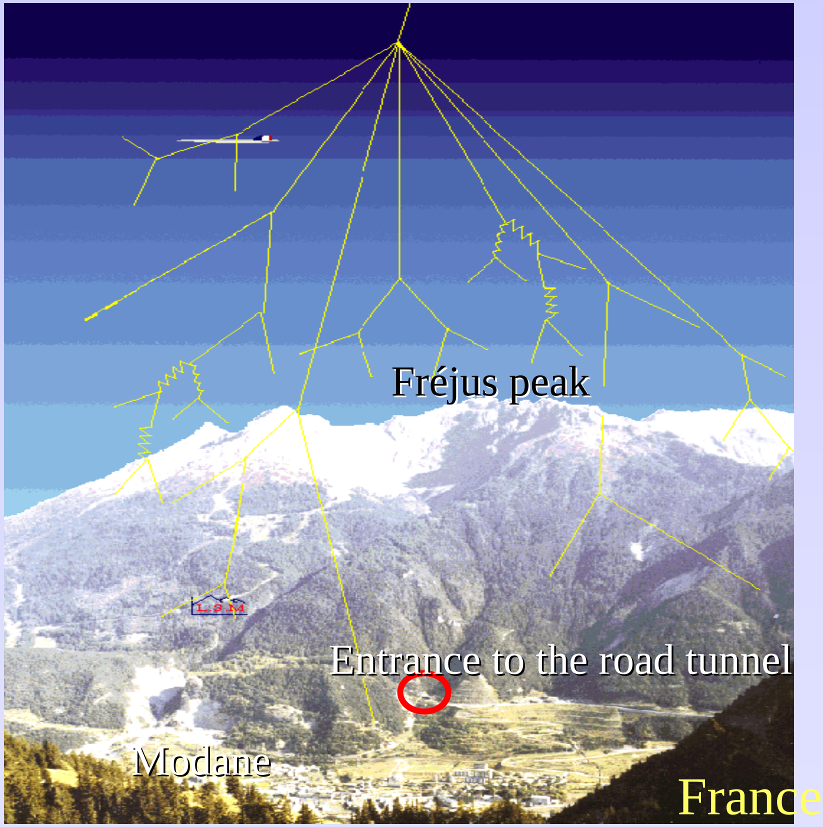
Mass Analyzer of Super Heavy Atoms (MASHA)



Search for SHE in nature theory and experiment



Detector installed in Modana (France)

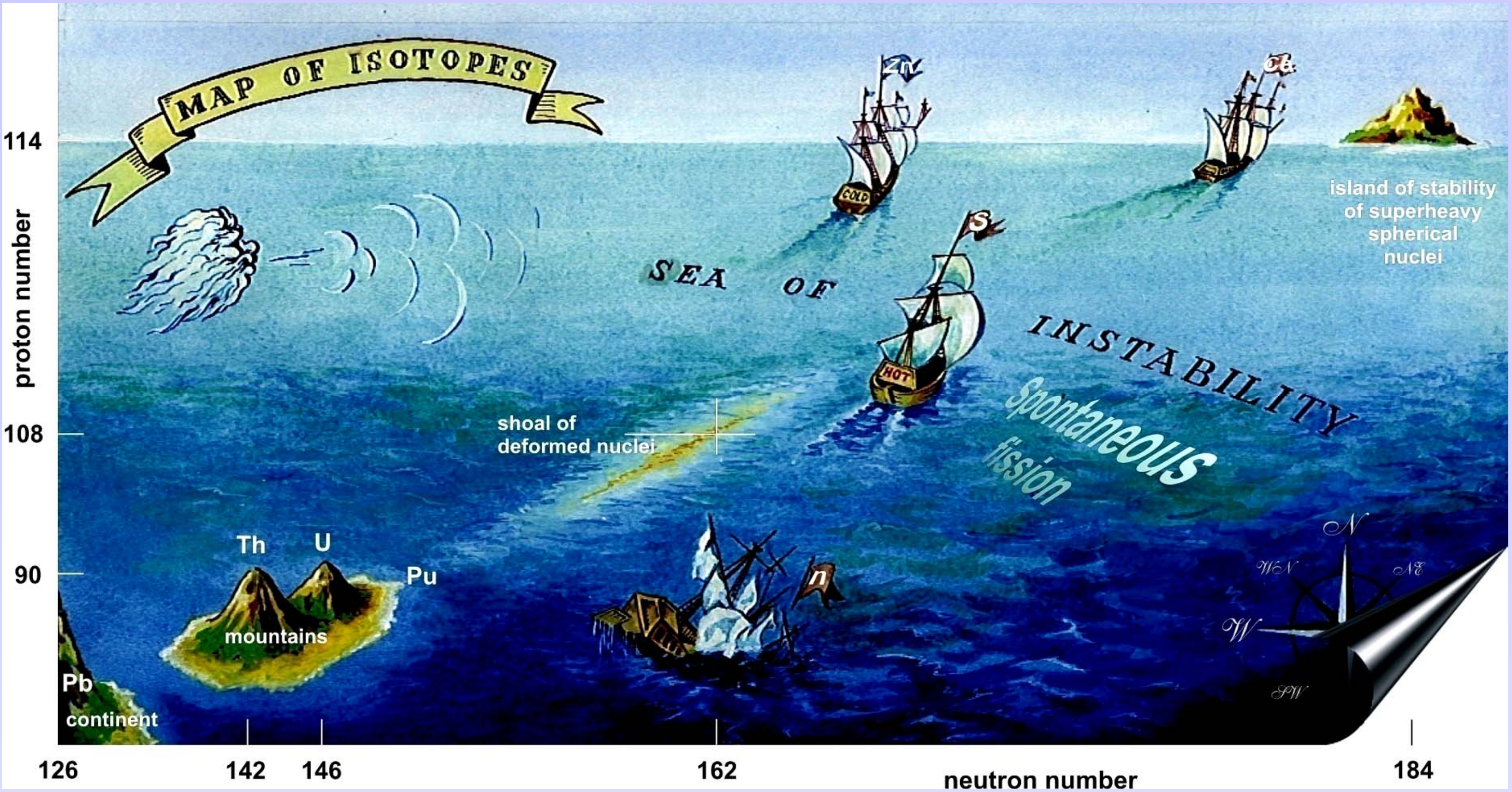


Bottom lines

- In the investigations carried out at different ^{48}Ca energies, 34 new nuclides were detected, all of them being evaporation products and their daughter nuclei in the region of Z = 104 – 118. and A = 266 – 294.
- Their sequential α-decays take place among unknown nuclei and are terminated by spontaneous fission.

The identification of the atomic numbers

- the mechanism of fusion reactions (excitation functions and cross bombardments ensuring variation of the proton and neutron numbers of the compound nucleus);
- by producing the same nuclei in different ways: as evaporation residues and as α-decay products of heavier nuclei.
- the decay properties of the nuclei in the decay sequences: the half-lives T_α and α-decay energies Q_α of even-even (and for many even-odd) isotopes, TKE-systematic;
- the radiochemical identification of the atomic number.



Thank you for your attention!
Many thanks to the organizers!!